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AQUIFER RESTORATION

Volume II. Appendices A thru G

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This two-volume report presents a summary of the state-of-the-art of aquifer restoration. Included are eight sections and seven appendices. The text includes sections on: (1) ground water pollution control through institutional measures, source control, stabilization/solidification methods, well systems, interceptor systems, capping and liners, sheet piling, grouting and slurry walls; (2) treatment of ground water via air stripping, carbon adsorption, biological treatment, chemical precipitation, and other treatment techniques; (3) in-situ chemical treatment and biological stabilization; (4) a protocol for aquifer restoration decision-making; and (5) techniques for aiding the decision-making process. The appendices (volume II) include: (1) case studies of aquifer restoration; (2) considerations regarding an aquifer restoration information center; (3) information for public participation in aquifer restoration decision-making; and (4) an annotated bibliography of 225 selected references. The stat-of-the-art of aquifer restoration is a rapidly changing technology, with many uses of single or combined techniques in planning or recently implemented. Unfortunately, few if any systems have yet reached shut-down levels for contaminants. Thus, effectiveness, duration and cost data are as yet incomplete but highly encouraging. A major need is for a systematic and comprehensive study of the cost-effectiveness of aquifer restoration technologies.

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FOREWORD

EPA is charged by Congress to protect the Nation's land, air and water systems. Under a mandate of national environmental laws focused on air and water quality, solid waste management and the control of toxic substances, pesticides, noise, and radiation, the Agency strives to formulate and implement actions which lead to a compatible balance between human activities and the ability of natural systems to support and nurture life.

The Robert S. Kerr Environmental Research Laboratory is the Agency's center of expertise for investigation of the soil and subsurface environment. Personnel at the laboratory are responsible for management of research programs to: (a) determine the fate, transport and transformation rates of pollutants in the soil, the unsaturated zone and the saturated zones of the subsurface environment; (b) define the processes to be used in characterizing the soil and subsurface environment as a receptor of pollutants; (c) develop techniques for predicting the effect of pollutants on ground water, soil and indigenous organisms; and (d) define and demonstrate the applicability and limitations of using natural processes, indigenous to the soil and subsurface environment, for the protection of this resource.

This project was initiated to provide a state-of-knowledge document of ground-water restoration methods describing available technologies and their applicability, and comparing methodologies and relative costs vs alternatives to restoration. The information found has been grouped into two volumes and includes sections on: (1) ground-water pollution control, (2) treatment of ground water, (3) in situ treatment, (4) a protocol for aquifer restoration decision-making, and (5) techniques for decision-making processes. The appendices include case studies of aquifer restoration and an annotated bibliography of 225 selected references. This compilation should be useful to those having a need for information about the cost-effectiveness of aquifer restoration technologies.

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ABSTRACT

This two-volume report presents a summary of the state-of-the-art of aquifer restoration. Included are eight sections and seven appendices. The text includes sections on: (1) ground water pollution control through institutional measures, source control, stabilization/solidification methods, well systems, interceptor systems, capping and liners, sheet piling, grouting and slurry walls; (2) treatment of ground water via air stripping, carbon adsorption, biological treatment, chemical precipitation, and other treatment techniques; (3) in-situ chemical treatment and biological stabilization; (4) a protocol for aquifer restoration decision-making; and (5) techniques for aiding the decision-making process. The appendices (volume II) include: (1) case studies of aquifer restoration; (2) considerations regarding an aquifer restoration information center; (3) information for public participation in aquifer restoration decision-making; and (4) an annotated bibliography of 225 selected references. The state-of-the-art of aquifer restoration is a rapidly changing technology, with many uses of single or combined techniques in planning or recently implemented. Unfortunately, few if any systems have yet reached shut-down levels for contaminants. Thus, effectiveness, duration and cost data are as yet incomplete but highly encouraging. A major need is for a systematic and comprehensive study of the cost-effectiveness of aquifer restoration technologies.

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APPENDIX A

CASE STUDIES OF AQUIFER RESTORATION MEASURES

INTRODUCTION

Three case studies on the application of aquifer restoration measures are presented in this appendix. The three cases are discussed according to a description of the ground water pollution problem, sources of contaminants and remedial actions. Information is also included on the aquifer restoration program of the New Jersey Department of Environmental Protection (NJDEP). Finally, summary information on 15 cases dealing with restoration using biological processes is presented. Case A on Tar Creek in Oklahoma summarizes an acid mine drainage problem and its adverse affect on the ground water. The Boone formation in the Tar Creek area is already affected and the contaminants are likely to spread to the Roubidoux formation unless effectively contained. No remedial actions have actually been implemented, although plans have been developed to restore the aquifer and to prevent further contamination. Case B presents information on the Gilson Road Site in New Hampshire. Treatability studies have been conducted for the Gilson Road site, and some remedial actions have been implemented. Case C deals with the Rocky Mountain arsenal and is drawn from work conducted by the U.S. Army. Remedial actions have been implemented to clean-up the alluvial aquifer, and further studies are in progress on source control measures.

Detailed information on aquifer restoration measures is not easily accessible. No assessment can be made of the long-term effectiveness of treatment methods. An economic assessment of various aquifer restoration strategies cannot be made due to a lack of detailed data on initial (capital) costs and operation and maintenance costs.

CASE A: TAR CREEK IN OKLAHOMA

Tar Creek is a small tributary of the Neosho River in northeastern Oklahoma. The creek runs through the Picher field which is now an abandoned mine area that was at one time one of the most productive lead and zinc mining districts in the United States. Actual production of lead and zinc from this area began around 1904 and continued until the late 1950's when all major operations were terminated. Mining began again in the early 1960's, but lasted only a few years. When the mining operations ceased and the dewatering pumps within the mines were removed, the mines started to flood due to natural recharge and surface water inflow. By 1979 the majority of the workings were completely flooded and surface discharge of poor quality water began.

The hydrogeology of the Tar Creek area is depicted in Figure A.1 (Hittman Associates, Inc., 1981). The major fresh water aquifer is the Roubidoux formation, which is comprised of 160 feet of cherty dolomite interspersed with several sandy sequences. The depth to this aquifer from the land surface is between 900 and 1000 feet. Overlying the Roubidoux are two dolomite formations called the Jefferson City and the Cotter. Overlying these dolomite deposits is the Boone formation, a 370-foot thick cherty limestone with spent lead and zinc deposits found from the old Picher mining district. The Boone formation was probably the major source of fresh water in the area before the era of large-scale mine watering. Overlying the Boone formation through most of the mining district is the Krebs group which consists principally of black fissile shale. The Krebs group serves as a confining layer, thus allowing artesian conditions to develop in the Boone formation.

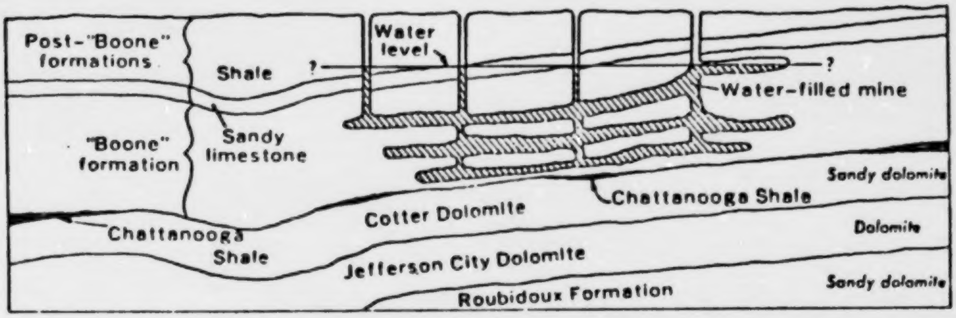

Post-"Boone" formations
Shale
Water level
?
?
Water-filled mine
"Boone" formation
Sandy limestone
Sandy dolomite
Chattanooga Shale
Cotter Dolomite
Chattanooga Shale
Dolomite
Jefferson City Dolomite
Roubidoux Formation
Sandy dolomite

Figure A.1: Hydrogeology of the Tar Creek Area (Hittman Associates, Inc., 1981)

The Tar Creek area is faced with two major problems as a result of the flooding of the mines and the resultant generation of acid mine water. First, the acid mine water follows the subsurface hydraulic gradient and moves laterally outward in the Boone formation and possibly downward into the Roubidoux formation. Second, after periods of intense precipitation, low quality mine waters discharge into the surface waters of the Tar Creek area. If the low quality water moves into the underlying Roubidoux formation it could start moving laterally and become a threat to this major fresh water aquifer. Dilution and mixing of the mine water with the more alkaline water of the Roubidoux formation will increase the pH; this could lead to precipitation of some of the heavy metal constituents in the mine water. However, it is anticipated that the effects of dispersion, adsorption and precipitation will not be enough to reduce the heavy metal concentrations below drinking water standards.

Although still in the planning stages, the Tar Creek situation represents an interesting case study of aquifer restoration and raises the following issues (Knox, Stover and Kincannon, 1982):

(1) Tri-State Involvement -- The geographical location of both the affected aquifer (Boone) and the threatened aquifer (Roubidoux) encompasses parts of three states: Oklahoma, Kansas, and Missouri. One of the key steps yet to be undertaken is the quantification of the amount of leakage, if any, from the polluted Boone formation down to the fresh water Roubidoux formation. Any reasonable estimate of leakage will require integrating well data from all three states.

(2) Surface Water Impacts -- Tar Creek represents a good example of polluted ground water adversely affecting the quality of surface water. Discharge of degraded quality water has been documented (Hittman Associates, Inc., 1981). This adds another facet to the problem since cleanup of the polluted ground water will not be enough. Measures will need to be

implemented to prevent surface water pollution. This could become a large task in that it will require identifying and sealing all avenues of escape for the ground water. These avenues can range from mine shaft openings to abandoned wells or boreholes from previous oil and gas field activities in the area.

(3) Financial Responsibility -- Another issue concerning Tar Creek, and one that is becoming all too common, is the question of financial responsibility, or who pays. The pollution problem cannot be attributed to a single company or individual. Hence any attempt to assign financial responsibility would be useless. Current preliminary funding has come from the "Superfund" program. However, preliminary estimates of the costs of cleanup range from $17 to 22 million. The "Superfund" program will not be able to pay for many cleanup programs of this magnitude.

(4) Abandonment -- One alternative that should be addressed in any aquifer restoration study is that of abandoning the polluted aquifer and development of a new source of fresh water. This has not been given much consideration in the Tar Creek area. Current planning involves a series of pump tests and new well networks to assess the potential for contaminant transport, to be followed by the development of specific alternatives for removing and treating the polluted water. These alternatives will then be compared to the alternative of abandoning the Roubidoux aquifer. The order should be reversed. Large sums of money could probably be saved by first examining the possibility of abandonment. It would be a waste if the aquifer characterization study showed no leakage from the Boone to the Roubidoux, with the polluted wells being due to faultily-cased wells through the Boone formation.

Sources of Contaminants

Lead and zinc mining activities expose sulfide-bearing minerals to moist, oxygen-rich air which oxidize the iron sulfide minerals. This has occurred in the Picher mining district. Pyrite-rich waste rock was discarded in mined out portions of drifts, with other sources of waste rock derived from sections of the shaley roof rock present in several mines. These rocks provided additional supplies of pyrite for oxidation. The oxidation of pyrite to form acid occurs in accordance with the following stoichiometric reaction (Hittman Associates, Inc., 1981):

$$FeS_2(s) + 7/2\ O_2 + H_2O \rightleftharpoons Fe^{+2} + 2SO_4^{2-} + 2H^+$$

For the above reaction to continue, both oxygen and water must be present at the mineral surface. As the Picher mine area flooded, the production of acid slowed because the water tended to restrict the diffusion of O_2 to the mineral surfaces. Additionally, the limestone-dolomite rocks within the formation allowed for natural neutralization to take place. As the limestone removed the hydrogen ions to form water and carbon dioxide, calcium ions went into solution, thus increasing both the total dissolved solids (TDS) and hardness. Eventually, the calcium ions precipitate as $CaSO_4$. This precipitate forms a thin film on the mineral surfaces, thus precluding further neutralization but also further inhibiting the production of acid mine water. Therefore, acid mine waters have been produced and are still being produced, albeit at a lower rate due to local natural phenomena.

Discharge of the acid mine water can disrupt the quality of surface waters. The surface waters will present a source of oxygen for the oxidation of the dissolved ferrous iron to ferric iron. The ferric iron then forms an insoluble ferric hydroxide with the release of more acidity in accordance with the following reactions (Hittman Associates, Inc., 1981):

$$Fe^{+2} + 1/4\ O_2 + H^+ \rightleftharpoons Fe^{+3} + 1/2\ H_2O$$

$$Fe^{3+} + 3H_2O \rightleftharpoons Fe(OH)_3(s) + 3H^+$$

The net result of these reactions is to decrease the pH of Tar Creek and to decrease its dissolved oxygen concentration. Also, the exposure of the low pH waters to the native creek bed minerals has resulted in increased aqueous concentrations of iron, lead, zinc, and cadmium.

Cessation of mining in the mid-1960's ended more than 50 years of water removal from the Boone formation. The many years of pumping resulted in a large cone of depression under water table conditions within the Boone formation. The cone of depression began filling via natural recharge through abandoned mine shafts, collapsed geological features, and abandoned oil and gas wells. These shafts and abandoned wells penetrate the overlying Krebs group confining layer that crops out at the surface. The water recharging the mine workings came in contact with the oxidation products that had formed earlier, and dissolution occurred rapidly. The majority of the mineralized water was confined to the approximate area where it was formed until the water level in the Boone formation reached equilibrium (Hittman Associates, Inc., 1981).

The potentiometric surface of the Boone formation continued to rise until it reached the base of the Krebs group. The shaley Krebs group became a confining layer, and the Boone formation began to behave as a confined aquifer as the potentiometric surface rose above the base of the Krebs group. By 1979, the potentiometric surface of the Boone formation exceeded the ground surface elevation in several locations. Surface discharge of acid mine water began to occur via abandoned or partially plugged oil or gas well exploration holes and mine air shafts. Confined conditions within the Boone formation are known to exist west of a north-south line connecting Commerce and Miami, Oklahoma. Surface discharge will continue as long as the potentiometric surface of the

Boone formation exceeds the ground surface and pathways through the Krebs group exist (Hittman Associates, Inc., 1981).

Discharge of the mine water to Tar Creek has already increased the TDS and heavy metal concentrations and, as noted earlier, decreased the dissolved oxygen concentration and pH. The pH has, however, remained moderate because there is not sufficient oxygen present to rapidly oxidize the ferrous ions, and because sewage treatment plant effluent, with a higher pH, is also discharged to Tar Creek or its tributaries (Hittman Associates, Inc., 1981).

Studies to Determine Remedial Actions

As a result of a preliminary study, the following three alternative remedial measures have been identified (Hittman Associates, Inc., 1981): (1) collection of surface water discharges with limited ground water pumpage and treatment; (2) ground water pumpage from flooded mine workings and collection of surface discharges and treatment; and (3) ground water pumpage from flooded mine workings and treatment with a surface sealing and diversion program to minimize direct recharge to the ground water system. To arrive at these alternatives, assumptions were made regarding the ground water recharge rate; necessary treatment plant capacity, operating life, heavy metals recovery, and siting criteria; and siting criteria for collection wells.

A state-of-the-art technology for treatment of acid mine drainage has been identified to consist of the following steps (Hittman Associates, Inc., 1981):

(1) Neutralization -- an ion exchange reaction that, in the case of acid mine drainage, combines hydroxyl ions (OH^-) with

acidic hydronium ions (H^+).

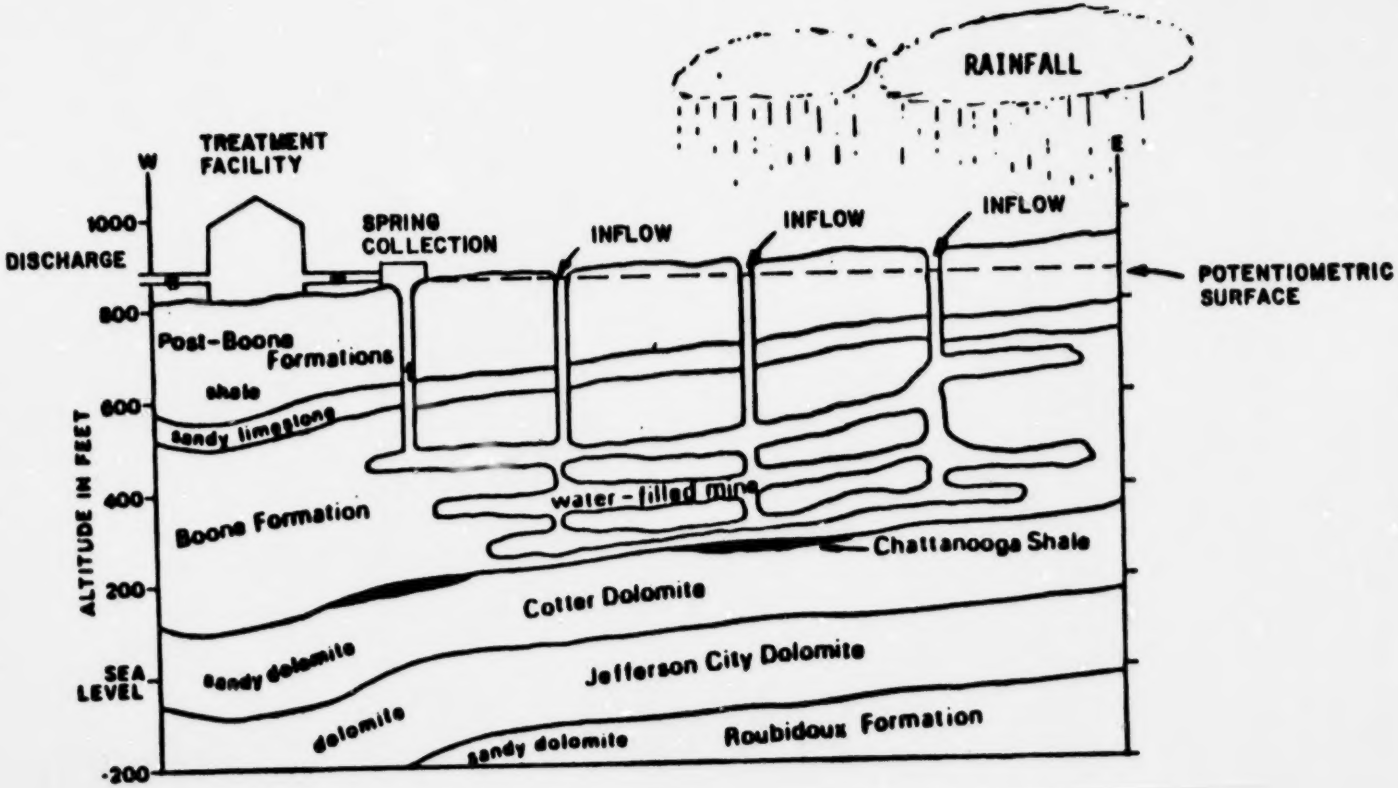
(2) Aeration -- a gas transfer process to increase the oxygen transfer rate and convert ferrous ions to ferric ions.

(3) Precipitation -- a chemical reaction based on decreasing the solubility of toxic and other metal ions.

(4) Sedimentation -- a physical process involving settling to remove suspended solids.

Carbon adsorption, ion exchange, reverse osmosis, electrodialysis, and ozonation were candidate technologies investigated before arriving at lime neutralization as the desired treatment method. The goals for the treatment system included the production of an acceptable effluent quality and minimum sludge volume with a maximum system reliability and acceptable capital and operating costs. Also, each treatment alternative has been planned to minimize the amount of land disturbed for the unit processes (Hittman Associates, Inc., 1981).

The Alternative I treatment system consists of aeration, flocculation and clarification (sedimentation). The conceptual design of this alternative is presented in Figure A.2 (Hittman Associates, Inc., 1981). Surface discharges from several locations would be collected and transported to the treatment plant via pipelines. The treatment plant processes are shown in Figure A.3 (Hittman Associates, Inc., 1981). Alternative I is designed principally to abate the surface discharge problem. Heavy metal concentrations in the treatment plant effluent are expected to be low; however, the effluent would be likely to have high hardness, high sulfate concentrations, and a low buffering capacity. The treated water will not be potable, but it would be suitable for agricultural and industrial applications. To clean-up the


RAINFALL
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TREATMENT FACILITY
SPRING COLLECTION
INFLOW
INFLOW
INFLOW
DISCHARGE
POTENTIOMETRIC SURFACE
1000
800
600
400
200
SEA LEVEL
-200
ALTITUDE IN FEET
Post-Boone Formations
shale
sandy limestone
Boone Formation
water-filled mine
Chattanooga Shale
Cotter Dolomite
sandy dolomite
Jefferson City Dolomite
dolomite
sandy dolomite
Roubidoux Formation

Figure A.2: Conceptual Design of Alternative I (Hittman Associates, Inc., 1981)

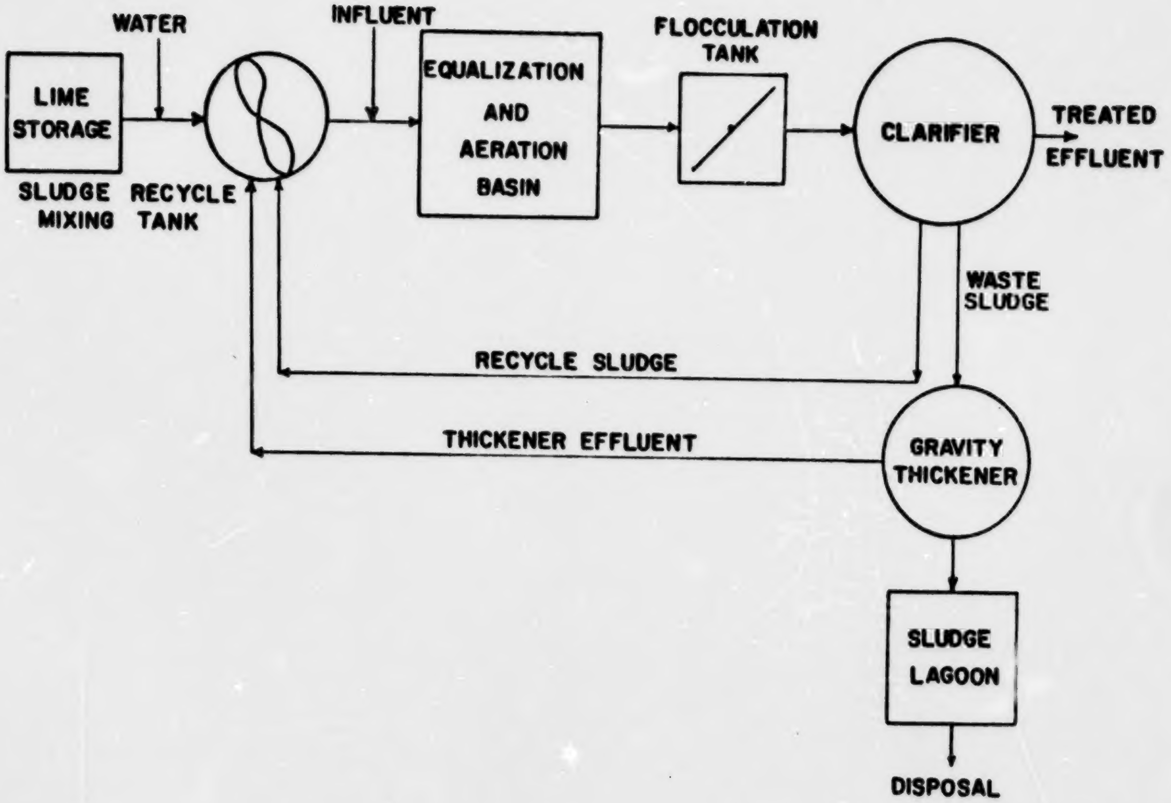
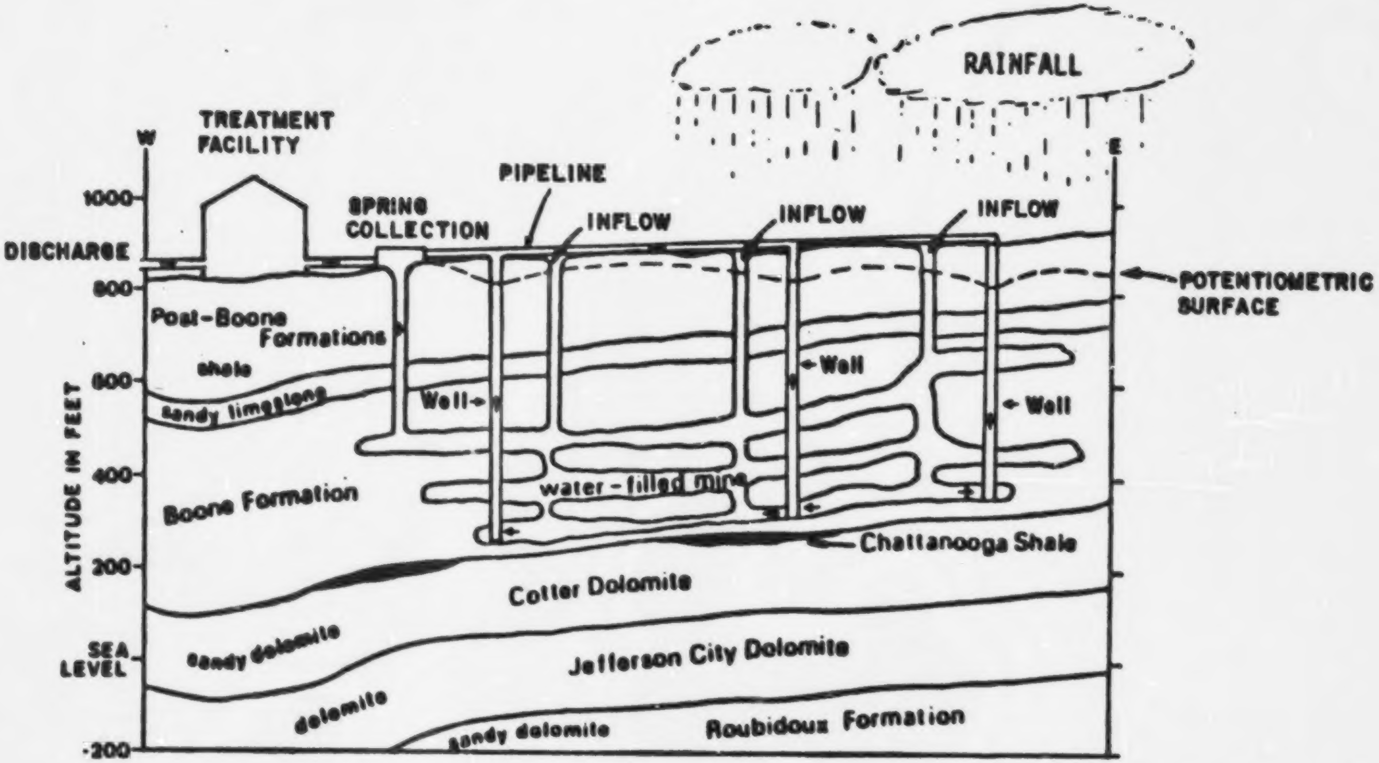

WATER
INFLUENT
FLOCCULATION TANK
LIME STORAGE
EQUALIZATION AND AERATION BASIN
CLARIFIER
TREATED EFFLUENT
SLUDGE MIXING
RECYCLE TANK
WASTE SLUDGE
RECYCLE SLUDGE
THICKENER EFFLUENT
GRAVITY THICKENER
SLUDGE LAGOON
DISPOSAL

Figure A.3: Acid Mine Drainage Treatment Plant -- Unit Processes (Hittman Associates, Inc., 1981)

acidic system in the Picher mining area, an estimated 36 years would be required.

Figure A.4 contains the conceptual design for Alternative II (Hittman Associates, Inc., 1981). As was the case for Alternative I, the treatment plant also consists of aeration, flocculation and clarification. Both natural discharges and pumped acid mine water from flooded shafts would be combined and transported to the treatment facility. Collector wells and monitoring wells, as shown in Figure A.5, will be required (Hittman Associates, Inc., 1981). Alternative II would be effective for treating surface discharges as well as the acid mine water located in the Boone formation. The treatment plant effluent would not be suitable for a potable water supply, but it could be used for agricultural and industrial needs. An estimated 23 years would be required to clean-up the Picher mining area with Alternative II.

Figure A.6 shows the conceptual design for Alternative III (Hittman Associates, Inc., 1981). The collection system would consist of 16 wells widely spaced to intercept and collect as much of the acid mine water as possible. Surface discharge holes would be sealed off using a packer and bentonite cement slurry and/or acid resistant grout. The treatment plant processes would be the same as proposed for Alternatives I and II. Alternative III has been designed to seal surface discharges, divert in-flow away from the mine area, and pump and treat ground water through a well collection system and treatment plant. As was the case for Alternatives I and II, the treatment plant effluent water quality would permit its usage only for agricultural and industrial purposes.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SEA LEVEL
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ALTITUDE IN FEET
POTENTIOMETRIC SURFACE
Post-Boone Formations
shale
sandy limestone
Well
Well
Well
Boone Formation
water-filled mine
Chattanooga Shale
Cotter Dolomite
sandy dolomite
Jefferson City Dolomite
dolomite
sandy dolomite
Roubidoux Formation

Figure A.4: Conceptual Design of Alternative II (Hittman Associates, Inc., 1981)

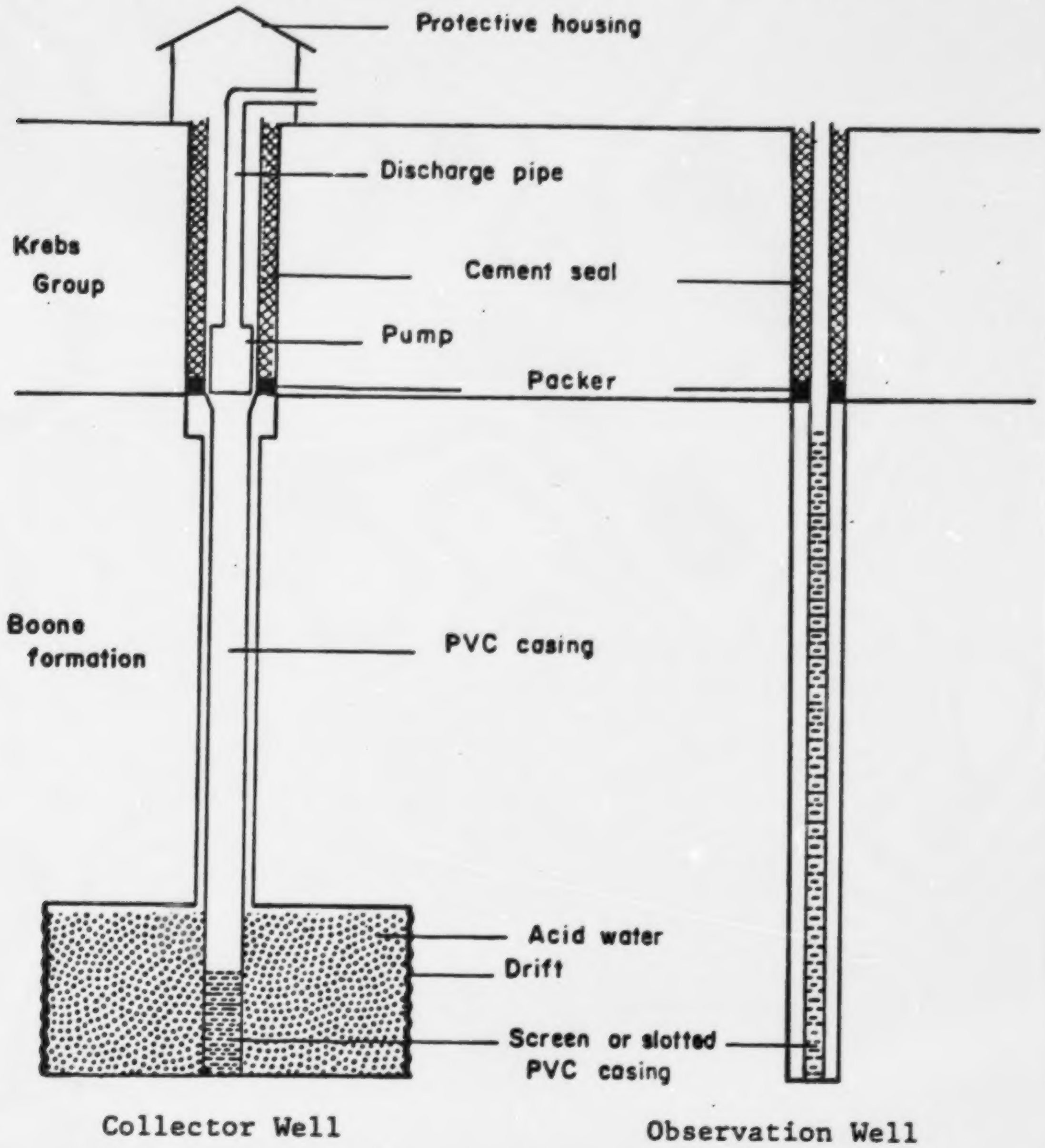
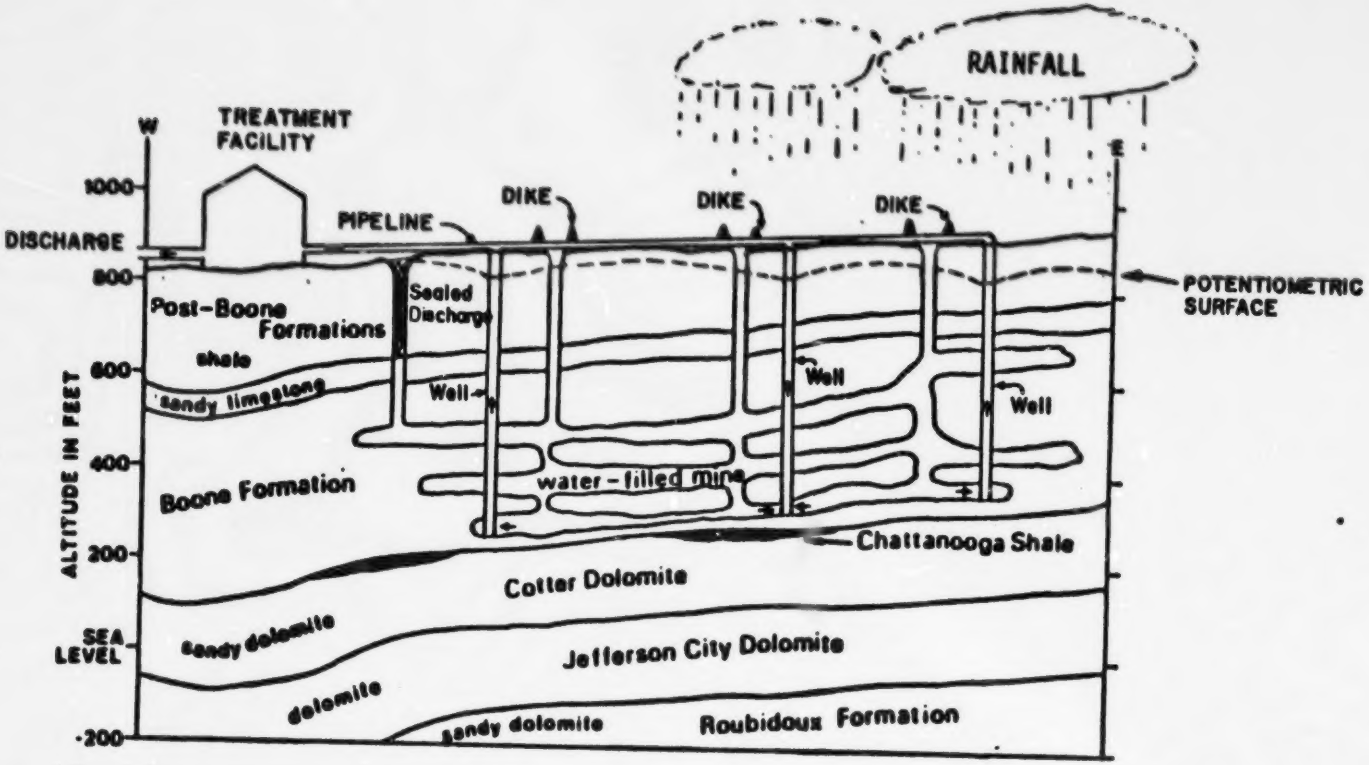

Protective housing
Discharge pipe
Krebs Group
Cement seal
Pump
Packer
Boone formation
PVC casing
Acid water
Drift
Screen or slotted PVC casing
Collector Well
Observation Well

Figure A.5: Conceptual Design for Collector and Monitoring (Observation) Wells (Hittman Associates, Inc., 1981)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DIKE
POTENTIOMETRIC SURFACE
Post-Boone Formations
shale
sandy limestone
Sealed Discharge
Well
Well
Well
Boone Formation
water-filled mine
Chattanooga Shale
Cotter Dolomite
sandy dolomite
Jefferson City Dolomite
dolomite
sandy dolomite
Roubidoux Formation

Figure A.6: Conceptual Design of Alternative III (Hittman Associates, Inc., 1981)

Alternative III is also expected to take 23 years to clean-up the Picher mining area.

Proposed Remedial Action

After evaluation of the three alternatives, Alternative II has been proposed as the optimum course of action for abatement of the Tar Creek acid mine drainage problem. Summaries of the capital and annualized costs for the three alternatives are in Tables A.1 and A.2 (Hittman Associates, Inc., 1981). Alternative II is designed to collect and treat the surface water discharges with the existing state-of-the-art technology. In addition, a system of 12 wells will withdraw 1200 gpm of acid mine water. The collector system facilitates acid mine water removal, thus preventing further contamination of the Boone formation and minimizing the potential for contamination of the Roubidoux formation. Final design will require the further conduction of problem characterization studies. Table A.3 lists some of the required studies (Knox, Stover and Kincannon, 1982).

CASE B: GILSON ROAD IN NEW HAMPSHIRE

A 6-acre site located in Nashua, New Hampshire was used as a borrow pit where, during the late 1960's, after much of the sand had been removed, an unapproved waste disposal operation was initiated, apparently to fill the excavation. Household refuse, demolition materials, chemical sludges, and hazardous liquid chemicals were all dumped at the site. This activity was first discovered in late 1970, and in the late 1970's all further disposal of hazardous wastes on the site was prohibited (Roy F. Weston, Inc., 1982).

Table A.1: Summary of Capital Costs for Tar Creek Alternatives I, II, and III (Hittman Associates, Inc., 1981)

CAPITAL COSTS-1981 DOLLARS	ALTERNATIVE 1 1 MGD Surface Water Collection & Treatment	ALTERNATIVE 2 2 MGD Surface & Ground Water Collection & Treatment	ALTERNATIVE 3 2 MGD Groundwater Collection & Treatment with Diversions
COLLECTION SYSTEM			
Collection Wells	$ 40,000	$ 104,000	$ 128,000
Observation Wells	$ 12,000	$ 39,000	$ 39,000
Pumps	$ 54,000	$ 116,000	$ 108,000
Piping	$ 167,000	$ 410,000	$ 469,000
Pump Housing	$ 10,000	$ 28,000	$ 32,000
Trenching	$ 178,000	$ 408,000	$ 457,000
Spring Collection	$ 40,000	$ 40,000	———
DIVERSION SYSTEM			
Sealing	———	———	$ 50,000
Diversion	———	———	$ 400,000
Consulting and Design	$ 45,000	$ 104,000	$ 124,000
Subtotal	$ 546,000	$1,249,000	$1,807,000
TREATMENT FACILITY			
Unit Processes			
Influent Pumping	$ 211,000	$ 430,000	$ 430,000
Flow Equalization	$ 156,000	$ 219,000	$ 219,000
Preliminary Treatment	$ 83,000	$ 187,000	$ 187,000
Chemical Addition	$ 34,000	$ 108,000	$ 108,000
Clarification	$ 156,000	$ 314,000	$ 314,000
Outfall Pumping	$ 48,000	$ 114,000	$ 114,000
Laboratory/Maintenance Building	$ 236,000	$ 480,000	$ 480,000
Gravity Thickening	$ 47,000	$ 101,000	$ 101,000
Sludge Handling	$ 61,000	$ 156,000	$ 156,000
Non-Construction Costs			
Consulting and Design	$ 62,000	$ 120,000	$ 120,000
Land	$ 50,000	$ 50,000	$ 50,000
Other non-construction costs	$ 68,000	$ 138,000	$ 138,000
Subtotal	$1,212,000	$2,417,000	$2,417,000
TOTAL CAPITAL COSTS	$1,758,000	$3,666,000	$4,224,000

Table A.2: Summary of Annualized Costs for Tar Creek Alternatives I, II, and III (Hittman Associates, Inc., 1981)

ANNUAL COSTS-1981 DOLLARS	ALTERNATIVE 1 1 MGD Surface Water Collection & Treatment	ALTERNATIVE 2 2 MGD Surface & Ground Water Collection & Treatment	ALTERNATIVE 3 2 MGD Groundwater Collection & Treatment with Diversions
COLLECTION SYSTEM O&M			
Manpower	$ 10,000/yr	$ 20,000/yr	$ 20,000/yr
Electrical	$ 12,000/yr	$ 18,000/yr	$ 21,000/yr
Replacement Costs	$ 9,000/yr	$ 40,000/yr	$ 37,000/yr
Pipeline Replacement	$ 3,000/yr	$ 10,000/yr	$ 10,000/yr
Subtotal	$ 34,000/yr	$ 88,000/yr	$ 88,000/yr
TREATMENT FACILITY O&M			
Manpower	$120,000/yr	$120,000/yr	$120,000/yr
Electrical	$ 35,100/yr	$ 70,200/yr	$ 70,200/yr
Chemicals	$ 73,000/yr	$142,200/yr	$142,200/yr
Maintenance & Repair	$ 72,000/yr	$138,000/yr	$138,000/yr
Subtotal	$300,100/yr	$470,400/yr	$470,400/yr
TOTAL ANNUAL OPERATION & MAINTENANCE COSTS	$334,100/yr	$558,400/yr	$558,400/yr
PLANT LIFE	36 years	23 years	23 years
TOTAL O&M COSTS OVER LIFE OF ALTERNATIVE	$12 million	$12.8 million	$12.8 millicn
CONSTRUCTION GRANT INTEREST RATE	7-3/8%	7-3/8%	7-3/8%
ANNUALIZED CAPITAL COSTS	$141,000/yr	$336,000/yr	$387,000/yr
TOTAL EQUIVALENT UNIFORM ANNUAL COSTS (EUAC)	$475,100/yr	$894,400/yr	$945,400/yr
TOTAL COST OVER LIFE OF ALTERNATIVE	$17.1 million	$20.6 million	$21.7 million

Table A.3: Additional Studies Needed for Tar Creek (Knox, Stover and Kincannon, 1982)

Phase		Step	
A.	Field Investigation	I.	Stream system and spring water analysis.
		II.	Ground water investigation.
		III.	Mine water investigation
		IV.	Investigation of pollution causation.
		V.	Drainage and diversion analysis.
		VI.	Public health impacts verification.
		VII.	Evaluation of the extent of the pollution problem.
B.	Feasibility Study	I.	Evaluate feasibility of treatment systems.
		II.	Evaluate alternative water supplies.
		III.	Comparison of abatement activities and alternative water supplies.
		IV.	Treatment plant feasibility (if needed).
		V.	Treatment plant design specifications.
		VI.	Alternative water supply feasibility (if needed).
		VII.	Tar Creek Task Force review of contractor recommendations.
		VIII.	Remedial actions.

The Gilson Road disposal site and property down gradient of the immediate disposal area is underlain by stratified, unconsolidated glacial desposits consisting mainly of two permeable, interfingering units (Roy F. Weston, Inc., 1982). These two units are mostly fine to medium sands or fine to coarse sands and gravels. The total thickness of these deposits range from less than 20 feet to nearly 90 feet. The permeable sands overlie a thin sequence of glacial tills having a maximum thickness of around 12 feet. It is very dense and contains admixtures of unstratified silt, sand and gravel. Metamorphic and, possibly, igneous bedrock underlies the site.

Ground water beneath the site occurs under unconfined or water-table conditions in the permeable stratified sands and gravels. It probably also occurs under semi-confined conditions in secondary fractures in the bedrock. It occurs under a gradient which is generally much less than one percent. Ground water testing and monitoring by atomic absorption and gas chromatograph/mass spectrometry showed contaminants in several wells near the dump site, including heavy metals, volatile organics, and extractable organics. The concentrations of heavy metals, volatile organics and extractable organics found in the ground water create concern for both the ambient air and water qualities. The primary compounds found in the contaminated ground water are shown in Table A.4 (Stover and Kincannon, 1982).

Sources of Contaminants

The major source of contaminants in ground water and the nearby surface waters, is the Gilson Road waste disposal site. The disposal

Table A.4: Primary Contaminants of Concern in Ground Water at the Gilson Road Site (Stover and Kincannon, 1982)

Heavy Metals	Volatile Organics	Extractable Organics
Arsenic	Tetrahydrofuran	1,4-Dichlorobenzene
Barium	1,1,1 Trichloroethane	1,2-Dichlorobenzene
Cadmium	Benzene	Naphthalene
Chromium	Trichloroethylene	2-Chlorophenol
Lead	Methyl Isobutyl Ketone	2-Nitrophenol
Mercury	Xylenes	Phenol
Selenium	Toluene	2,4-Dimethylphenol
Silver	Ethylbenzene	O-Cresol
Copper		M-Cresol
Iron		Benzoic Acid
Manganese		Pentachlorophenol
Nickel		
Zinc		

site is located less than 1000 feet from Lyle Reed Brook, a small stream tributary to the Nashua River. Any surface discharge from the site would likely flow into this brook which has a total drainage area of about 1.5 square miles. The flow from Lyle Reed Brook enters the Nashua River about seven miles upstream of the confluence with the Merrimack River. The ground water from underneath the disposal site migrates to Lyle Reed Brook and thus contaminates it. Volatile organic compounds are the main concern due to their presence, in extremely high concentrations, in the ground water. Volatilization of the compounds from surface waters into the ambient air may have adverse effects on the surrounding residents, flora and fauna (Roy F. Weston, Inc., 1982).

Studies to Determine Remedial Actions

A grant from the U.S. Environmental Protection Agency funded under the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA or Superfund) for clean-up of the site required that an interim report be prepared for dealing with the feasibility of ground water treatment. On the basis of the environmental effects, monetary costs, technical feasibility, and long-term operational considerations, the most cost-effective solution for alleviating the condition of contaminated ground water at the hazardous waste dump site was to be determined.

Ambient air and water quality criteria were evaluated, and appropriate ambient standards were defined. A thorough literature search was conducted to identify all applicable treatment technologies (Stover and Kincannon, 1982). The best treatment process was to be selected based on process feasibility, demonstrated reliability and costs. Selection of the most cost-effective alternative was based on a comparison of five options. The lowest cost, technically feasible option was considered to be the most cost-effective alternative (Knox, Stover and Kincannon, 1982).

Conventional wastewater treatment technologies directly applicable for clean-up of this contaminated ground water were identified to be chemical precipitation, air stripping, steam stripping, activated carbon adsorption, and biological treatment. These processes could be aggregated in a variety of combinations to achieve various treatment levels. The evaluation of these unit processes by laboratory bench-scale treatability studies presented a challenge in selecting the best unit processes and their combinations. The treatability studies indicated that the heavy metals, volatile organics and extractable organics of concern could be successfully treated (removed) by two alternative processes (Stover and Kincannon, 1982). One process consisted of metals removal by chemical precipitation followed by steam stripping and activated carbon adsorption. The alternate process consisted of the combined physical/chemical and biological treatment scheme of chemical precipitation, steam stripping and biological treatment.

Heavy metals can be removed from water by chemical precipitation, at an optimum pH. Three types of chemical systems used have been identified as carbonate systems, hydroxide systems, and sulfide systems. Jar test studies on the Gilson Road site ground water indicated that lime (hydroxide) addition was the best choice. Variation of pH and chemical dosages indicated the best operating pH to be 10.0. The pH titration characteristics of raw water and treated water for metals removal are shown in Figure A.7 (Stover and Kincannon, 1982). The level of heavy metals in the raw water and in the treated water at the optimum pH of 10 are shown in Table A.5 (Stover and Kincannon, 1982). The sludge produced during the metals removal step will have to be removed from the liquid stream and treated. Activated carbon was also effective in removal of heavy metals, with Table A.5 showing the results (Stover and Kincannon, 1982). The effectiveness of activated carbon in removal of heavy metals was found to be comparable to lime treatment. Some of the important design factors identified in this treatability study were:

(1) Best chemical addition system
(2) Optimum chemical dose
(3) pH considerations
(4) Rapid mix requirements
(5) Flocculation requirements
(6) Sludge production
(7) Sludge flocculation, settling and dewatering characteristics

Volatile organic compounds are the contaminants of major concern in ground water from the Gilson Road site. The treatment methods considered included air stripping, steam stripping, activated carbon adsorption, ultraviolet light/ozone, biological treatment, wet oxidation, flash evaporation, distillation, and membrane separation processes. Due to the excessive contamination, the alternatives were narrowed down to air stripping and steam stripping as potentially the most effective. The results of the stripping experiments in terms of total organic carbon removals (TOC) are shown in Figure A.8 (Stover and Kincannon, 1982). As shown in Table A.6, steam stripping was found to be the most successful in removal of all the volatile organics (Stover

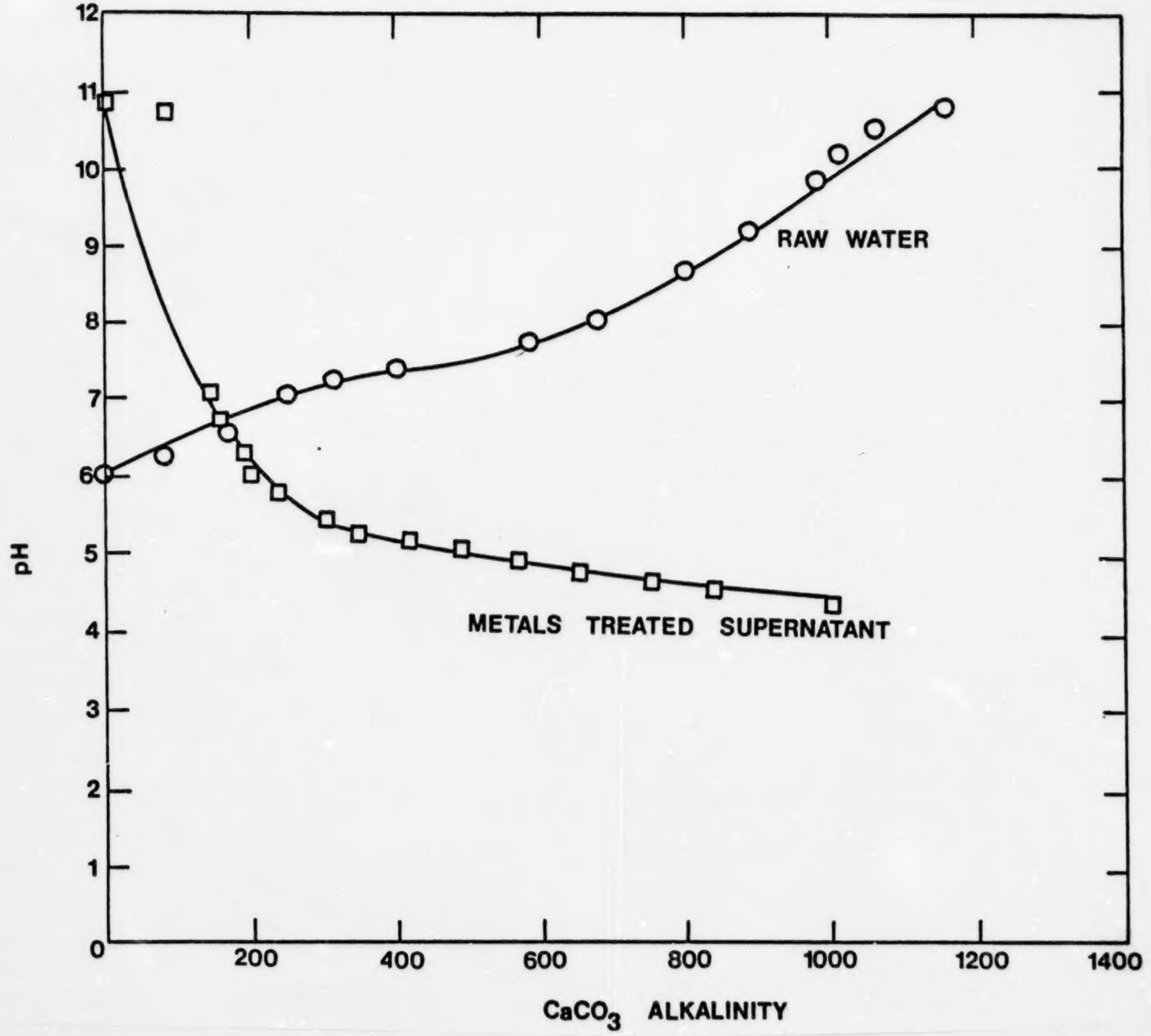


Figure A.7: pH Titration Characteristics of Raw and Treated Ground Water from the Gilson Road Site (Stover and Kincannon, 1982)

Table A.5: Test Results from Metals Removal Studies of Ground Water from the Gilson Road Site (Stover and Kincannon, 1982)

Parameter	Raw Water	Lime Metals Treatment	Activated Carbon (3,600 mg/ℓ	Activated Carbon 7,200 mg/ℓ	Activated Carbon 14,400) mg/ℓ
Arsenic (mg/ℓ)	0.10	0.03	0.03	0.03	0.03
Barium (mg/ℓ)	0.25	0.16	0.05	0.05	0.04
Cadmium (mg/ℓ)	0.006	0.001	0.001	0.001	0.001
Chromium (mg/ℓ)	0.07	0.01	0.01	0.01	0.01
Lead (mg/ℓ)	0.01	0.006	0.006	0.005	0.004
Mercury (mg/ℓ)	<0.001	<0.001	<0.001	<0.001	<0.001
Selenium (mg/ℓ)	<0.001	<0.001	<0.001	<0.001	<0.001
Silver (mg/ℓ)	<0.001	<0.001	<0.001	<0.001	<0.001
Copper (mg/ℓ)	0.06	0.03	0.03	0.03	0.03
Iron (mg/ℓ)	390	0.40	0.40	0.27	0.27
Manganese (mg/ℓ)	75	0	0	0	0
Nickel (mg/ℓ)	1.23	0.30	0.30	0.30	0.30
Zinc (mg/ℓ)	0.69	0.31	0.30	0.30	0.30

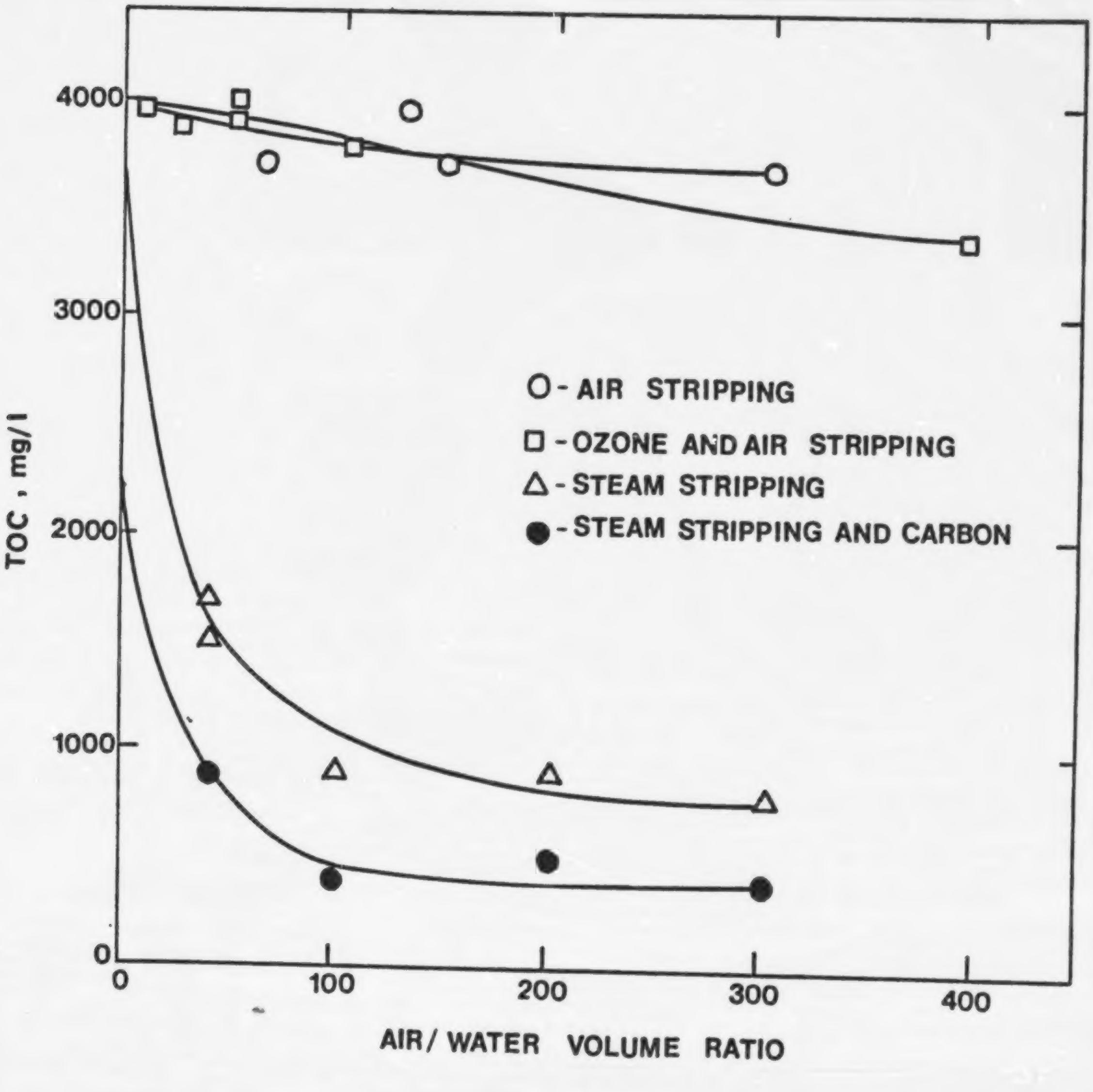


Figure A.8: TOC Removal by Air and Steam Stripping of Ground Water from the Gilson Road Site (Stover and Kincannon, 1982)

Table A.6: Volatile Organics Removal During Stripping Studies of Ground Water from the Gilson Road Site (Stover and Kincannon, 1982)

Volatile Organic Compound, μg/ℓ	Raw Water	Air Stripping	Ozone and Air Stripping	Steam Stripping
Tetrahydrofuran	22,000	ND	ND	ND
1,1,1 Trichloroethane	150,000	7,600	ND	ND
Benzene	68,750	36,000	375	ND
Trichloroethylene	338,000	189,000	5,195	ND
Methyl Isobutyl Ketone	76,400	18,500	1,000	ND
Xylenes	517	ND	ND	ND
Toluene	92,000	6,600	5,300	ND
Ethylbenzene	23,500	ND	ND	ND

ND - None detected (no peaks on chromatograms)

Results are from best runs at higher air-to-water ratios.

and Kincannon, 1982). Addition of activated carbon increased the overall TOC removal and removal of extractable organics.

Extractable organics present in ground water from the Gilson Road site include phenols, cresols, napthalenes, phthalates, organic acids, and alcohols. Steam stripping is effective in their removal, with Table A.7 showing the test results of the steam stripping runs (Stover and Kincannon, 1982). Activated carbon adsorption isotherm studies were conducted with raw water, metals treated water, and steam stripped water. Activated carbon was not effective in removing high levels of TOC, but useful for certain extractable organics as shown in Table A.8 (Stover and Kincannon, 1982). Activated carbon does not readily adsorb organic acids and alcohols. Biological treatment was also considered as an alternative for removal of extractable organics. An activated sludge system was used with seed sludge from several systems already in operation. The system was operated by feeding metals treated water on a food-to-microorganism (F/M) ratio of about 0.3 to 0.5 (BOD_5/VSS), and wasting sludge on a daily basis by the fill-and-draw operating procedure. The test results are presented in Table A.9 (Stover and Kincannon, 1982). Activated sludge was found to nave an excellent potential for removal of TOC and specific extractable organic compounds.

More detailed information is required prior to the final design of a treatment system to insure an effective, reliable design. Pilot-scale studies are required to refine the final design of the steam stripper, and since metals removal is required prior to steam stripping, both of these processes must be piloted at the Gilson Road site. These two processes will accomplish removal of specific organics and inorganics of

Table A.7: Removal of Extractable Organics by Steam Stripping of Ground Water from the Gilson Road Site (Stover and Kincannon, 1982)

Extractable Organic Compound, μg/ℓ	Raw Water	Treated Water
1,4-Dichlorobenzene	35	ND
1,2-Dichlorobenzene	5	ND
Naphthalene	≤1	≤1
2-Chlorophenol	540	ND
2-Nitrophenol	15	6
Phenol	370	20
2,4-Dimethylphenol	20	ND
O-Cresol	80	25
M-Cresol	220	ND
Benzoic Acid	1,230	ND
Pentachlorophenol	40	2

Table A.8: Test Results from Various Activated Carbon Studies of Ground Water from the Gilson Road Site (Stover and Kincannon, 1982)

Extractable Organic Compound, μg/ℓ	Raw Water	Lime Treated	PAC Treated	Lime and PAC Treated	Steam Stripped and PAC Treated
1,4-Dichlorobenzene	35	35	ND	≤ 1	ND
1,2-Dichlorobenzene	5	5	ND	2	ND
Naphthalene	≤ 1	≤ 1	ND	≤ 1	ND
2-Chlorophenol	540	540	8	6	≤ 1
2-Nitrophenol	15	15	≤ 1	8	ND
Phenol	370	370	≤ 1	ND	ND
2,4-Dimethylphenol	20	20	2	≤ 1	ND
O-Cresol	80	80	10	ND	ND
M-Cresol	220	220	≤ 1	ND	ND
Benzoic Acid	1,230	1,230	≤ 1	ND	ND
Pentachlorophenol	40	40	≤ 1	ND	ND

ND - None detected (no peaks on chromatograms).

Lime treated water to pH 10.0.

Lime and PAC samples adjusted to pH 10.0, then the supernatant was adjusted to pH 6.5 with sulfuric acid for PAC treatment.

PAC - Nuchar Aqua (Westvāco) and Carborundum PAC 20

Table A.9: Test Results from Batch Activated Sludge Studies of Ground Water from the Gilson Road Site (Stover and Kincannon, 1982)

Volatile Organic Compound, µg/ℓ	Batch Run Number 1 Feed(time 0)	 Time (12 hrs)	Batch Run Number 2 Feed (time 0)	 Time(8 hrs)
Tetrahydrofuran	ND	ND	ND	ND
1,1,1 Trichloroethane	3776	78	2513	ND
Benzene	13,800*	330	1058	1897*
Trichloroethylene		3920	3316	
Methyl Isobutyl Ketone	866	143	3385	1098
Xylenes	ND	ND	ND	ND
Toluene	156	11	2115	25
Ethylbenzene	ND	ND	1123	ND
Extractable Organic Compound, µg/ℓ				
1,4-Dichlorobenzene	28	ND	≤10	ND
1,2-Dichlorobenzene	≤10	ND	≤10	ND
Naphthalene	≤10	ND	≤10	ND
2-Chlorophenol	50	ND	30	ND
2-Nitrophenol	ND	ND	ND	ND
Phenol	20	ND	12	ND
2,4-Dimethylphenol	ND	ND	ND	ND
O-Cresol	60	ND	25	ND
M-Cresol	ND	ND	ND	ND
Benzoic Acid	ND	ND	3	ND
Pentachlorophenol	15	ND	ND	ND

ND - None detected (no peaks on chromatograms)

* - Benzene and Trichloroethylene peaks combined into one peak.

primary concern; however, the treated water will remain high in TOC, COD, and BOD. Biological treatment will be required following steam stripping to reduce these parameters to acceptable levels. Additional biological treatability studies will be required to define the biokinetic descriptive constants and the treatment performance reasonably achievable by biological treatment. This information will be required for full-scale design and can be developed from laboratory bench-scale, continuous flow systems.

Remedial Actions Implemented

The remedial actions considered for implementation consisted of installation of a clean water exclusion system consisting of a slurry wall and surface cap containing a twenty acre site determined to be highly contaminated. A ground water collection system would then be installed to deliver the contaminated ground water to a treatment plant for removal of the heavy metals, volatile organics, and extractable organics. The treated water would then be returned to the contained area for the purpose of flushing the remaining contaminated ground water. The specific selected plan consisted of the following (Roy F. Weston, Inc., 1982):

(1) A three-foot thick slurry wall, fully enclosing the 20 acre site.

(2) An impermeable surface cap consisting of a 40 mil polyethylene liner.

(3) Three to four ground water collection wells.

(4) A ground water treatment facility.

(5) A ground water reinjection system using surface trenches.

The treatability studies for designing the ground water treatment facility are summarized in Table A.10 (Stover and Kincannon, 1982). From an analysis of this treatability program, it was determined that the combined unit processes of metals removal, steam stripping, and biological treatment was the most feasible treatment alternative. The second alternative of metals removal, steam stripping, and activated carbon adsorption would remove the specific inorganic and organic compounds of concern; however, the residual organics measured as TOC would still be too high.

One essential aspect of the evaluation of the life time cost of the treatment facility and the clean-up or restoration potential of the aquifer was the length of time required to achieve a desired level of treatment. Therefore, a laboratory scale experiment was designed to simulate flushing of the aquifer to estimate the number of times the ground water would have to be turned over, or flushed through the contaminated soil, to achieve the desired level of water quality. In this experiment a sample of uncontaminated soil from the site was soaked in contaminated ground water under controlled conditions, and then flushed with clean water under controlled conditions (Stover and Kincannon, 1982). From this experiment, a relationship between pumping flow rate and required aquifer flushing time was determined for achieving the desired ground water quality.

The construction of the slurry wall enclosing the twenty acre site and the impermeable surface cap have been completed. Additional second phase pilot-scale studies have been initiated to finalize the design for metals removal and steam stripping. The effluent from this pilot plant

Table A.10: Summary of Treatability Studies of Ground Water from the Gilson Road Site (Stover and Kincannon, 1982)

				Activated Carbon		
Parameter	Raw Water	Metals Treatment	Steam Stripping	(6,000 mg/ℓ)	(24,000 mg/ℓ)	Biological Treatment
Tetrahydrofuran (μg/ℓ)	22,000	--	ND	--	--	ND
1,1 1 Trichloroethane (μg/ℓ)	150,000	--	ND	--	--	ND
Benzene (μg/ℓ)	68,750	--	ND	--	--	1,897*
Trichloroethylene (μg/ℓ)	338,000	--	ND	--	--	1,098
Methyl Isobutyl Ketone (μg/ℓ)	76,400	--	ND	--	--	ND
Xylenes (μg/ℓ)	ND	--	ND	--	--	25
Toluene (μg/ℓ)	92,000	--	ND	--	--	ND
Ethylbenzene (μg/ℓ)	23,500	--	ND	--	--	ND
1,4 Dichlorobenzene (μg/ℓ)	35	35	17	ND	ND	ND
1,2 Dichlorobenzene (μg/ℓ)	5	5	ND	ND	ND	ND
Naphthalene (μg/ℓ)	≤1	≤1	≤1	≤1	ND	ND
2-Chlorophenol (μg/ℓ)	540	540	40	≤1	≤1	ND
2-Nitrophenol (μg/ℓ)	15	ND	6	ND	ND	ND
Phenol (μg/ℓ)	370	ND	20	ND	ND	ND
2,4 Dimethylphenol (μg/ℓ)	20	ND	ND	ND	ND	ND
O-Cresol (μg/ℓ)	80	80	25	ND	ND	ND
M-Cresol (μg/ℓ)	220	220	ND	≤1	ND	ND
Benzoic Acid (μg/ℓ)	1,230	1,230	ND	ND	ND	ND
Pentachlorophenol (μg/ℓ)	40	40	40	8	2	ND

ND - No peaks on chromatograms

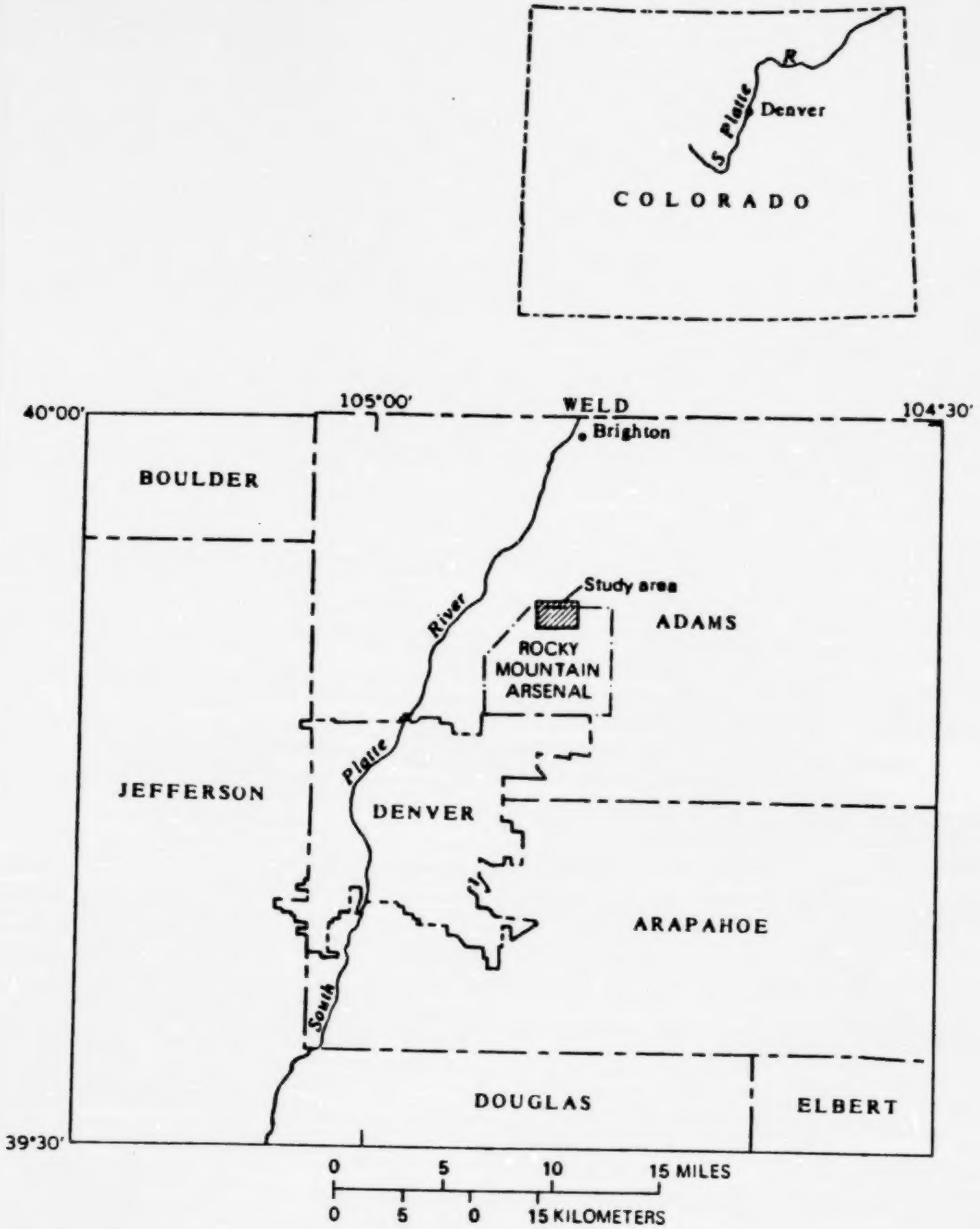
* - Benzene and Trichloroethylene peaks combined into one peak

will then be subjected to the bench-scale biological studies (Knox, Stover and Kincannon, 1982).

CASE C: ROCKY MOUNTAIN ARSENAL

The Rocky Mountain Arsenal was established in 1942 by the U.S. Army, and it is located 27 miles northeast of Denver, Colorado (Warner, 1979). Figures A.9 and A.10 show the location of the arsenal and the surrounding area (Warner, 1979; and Shukle, 1982). During World War II incendiary munitions and various toxic chemicals were produced. As a result of waste leakage from open pits and lagoons, the ground water in vicinity of the arsenal became contaminated over the years. Since 1947, private industry has leased many of the arsenal facilities for production of pesticides. Liquid wastes generated were discharged to a series of unlined waste storage basins. Crop damage detected at the northwest boundary of the arsenal in 1954 was suspected to be due to seepage from the basins. The crops were being irrigated with water from the alluvial aquifer underlying the basins (Shukle, 1982).

The alluvium consists of silts and clays overlying sands and gravels, with thickness ranging from 20 to 30 feet. An illustration of ground water contours and bedrock highs in the arsenal area is presented in Figure A.11 (Warner, 1979). The Denver formation is composed of clay shale and clay stone with some sand units. Alluvium is saturated within 5 to 15 feet of the ground surface and an estimated 64,000 gallons per day of the ground water flows at the north boundary of the arsenal. Ground water flows into the South Platte river, which appears to act as a boundary for further underground migration (Shukle, 1982).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S. Platte
Denver
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105°00′
WELD
104°30′
40°00′
Brighton
BOULDER
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JEFFERSON
Platte
DENVER
ARAPAHOE
South
DOUGLAS
ELBERT
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0
5
10
15 MILES
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5
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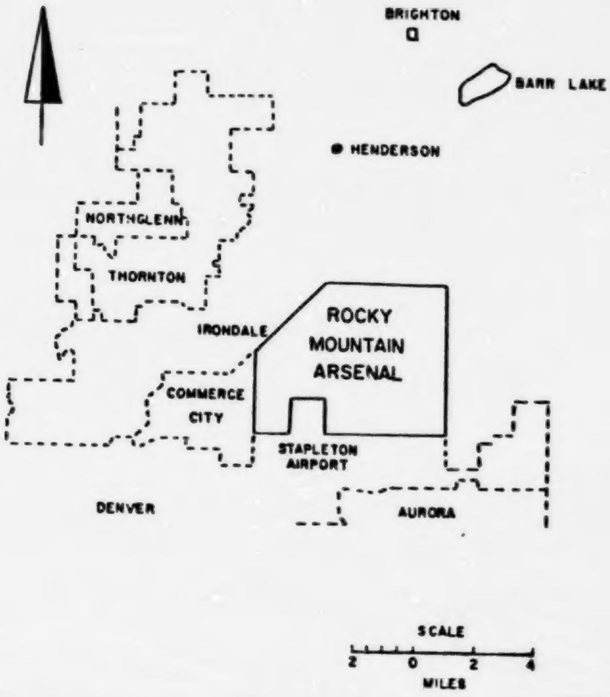
15 KILOMETERS

Figure A.9: Location of Rocky Mountain Arsenal (Warner, 1979)


BRIGHTON
BARR LAKE
HENDERSON
NORTHGLENN
THORNTON
IRONDALE
ROCKY MOUNTAIN ARSENAL
COMMERCE CITY
STAPLETON AIRPORT
DENVER
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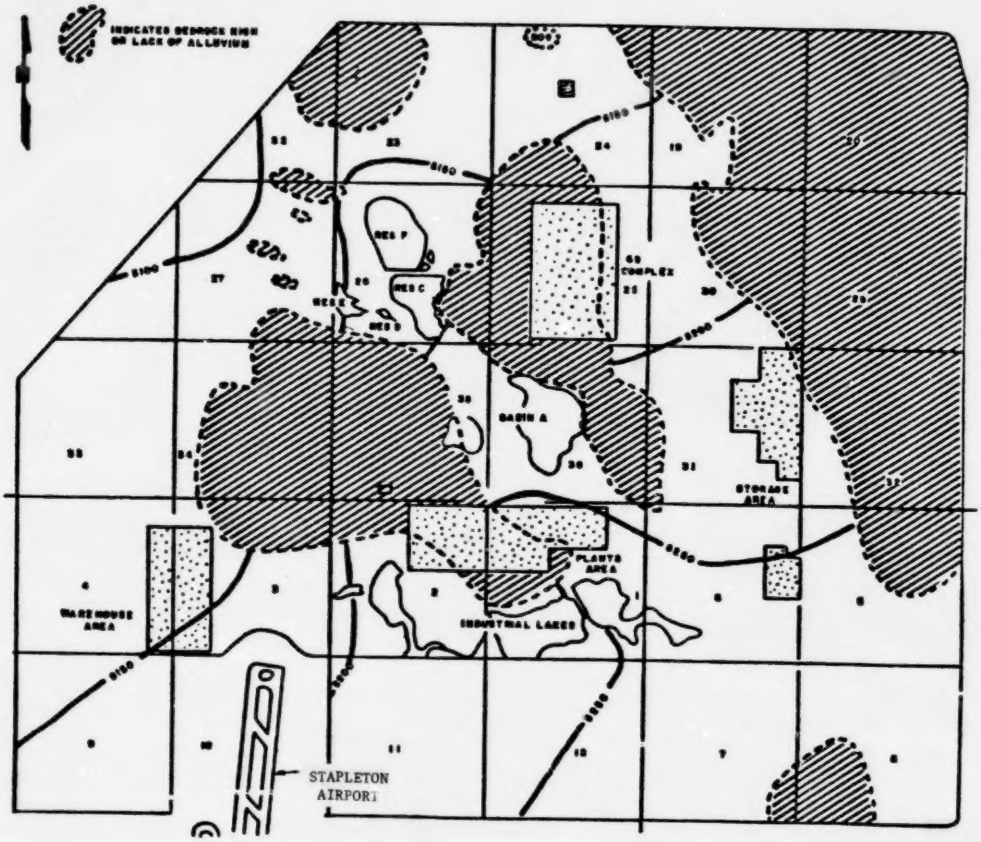
SCALE
2
0
2
4
MILES

Figure A.10: Vicinity Map of Rocky Mountain Arsenal (Shukle, 1982)


INDICATES BEDROCK HIGH OR LACK OF ALLUVIUM
23
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RES F
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RES E
RES D
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BASIN A
34
31
STORAGE AREA
PLANTS AREA
INDUSTRIAL LAKES
WAREHOUSE AREA
11
7
STAPLETON AIRPORT

Figure A.11: Ground Water Contours and Bedrock Highs at the Rocky Mountain Arsenal (Warner, 1979)

In April 1975, the Colorado Department of Health issued orders to the U.S. Army and Shell Chemical Company relative to the identification of diisomethylphosphonate (DIMP) and dicloropentadiene (DCPD) in seepage from the north boundary of the arsenal. The orders required: (1) cease the discharge of these compounds to surface and subsurface waters; (2) develop a plan to accomplish the cessation of the discharge; and (3) implement a monitoring program to demonstrate compliance with the orders (Shukle, 1982). The stringent water rights within the state of Colorado also required that treated ground waters be reinjected so as not to disrupt subsurface flow patterns (Shukle, 1982).

Sources of Contamination

As mentioned earlier, the main source of ground water contamination at the arsenal is the seepage from the waste storage basins. A monitoring program which consists of approximately 92 ground water wells and 19 surface water locations, has provided a good understanding of the conditions, plus has identified new organic contaminants and new sources and areas of contamination. In addition to the disposal basins, the railroad yard, the manufacturing and chemical storage area, and miscellaneous burial sites have also impacted ground water under the arsenal. Various chemical compounds have been found in the ground and surface waters sampled near the arsenal. A list of the chemicals found is provided in Table A.11 (Hager and Loven, 1982). Diisomethylphosphonate (DIMP) and dicycloropentadiene (DCPD) were identified as the major contaminants present (Hager and Loven, 1982). The extent of ground water contamination in the arsenal area has been

Table A.11: Ground Water Contaminants at North Boundary of Rocky Mountain Arsenal (Hager and Loven, 1982)

Compound	Concentration (μg/1)	
	PW2 (1)	PW3 (2)
Aldrin	< 2.0	< 2.0
Dieldrin	4.5	< 2.0
Dichloropentadiene	1000	82
Diisomethyl phosphonate	530	2800
Endrin	8.6	< 2.0
Dibromochloropropane	7.6	< 1.0
p Chlorophenylmethyl		
sulfide	68.3	< 10.0
solfoxide	53.3	< 10.0
sulfone	40.5	< 10.0

(1) Monitoring well PW2

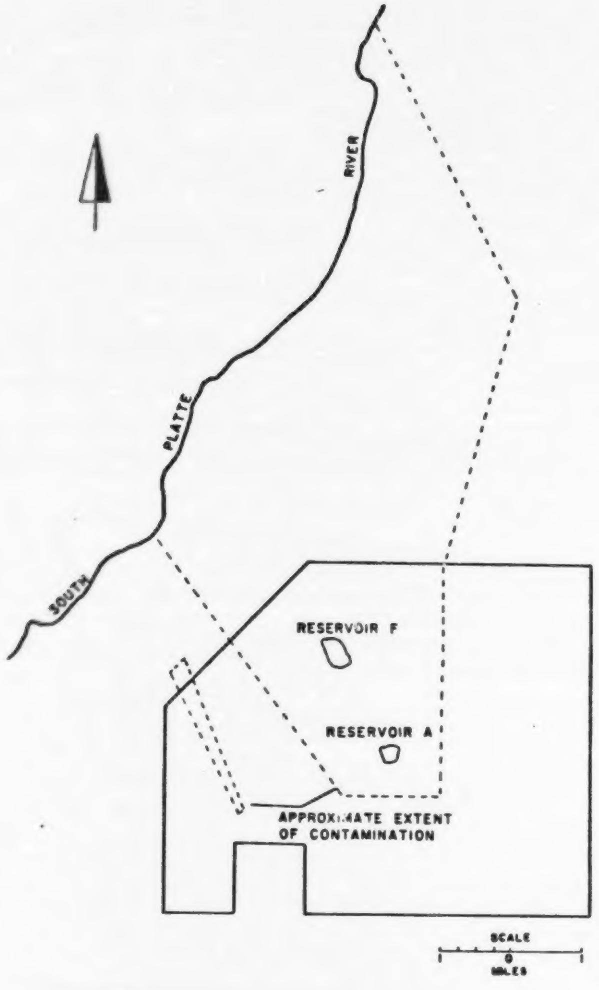
(2) Monitoring well PW3

identified as shown in Figure A.12 (Shukle, 1982). The contaminants in the alluvial aquifer are not uniformly distributed and some wells encounter higher concentrations than others. There are also variations in the types of contaminants in different wells (Shukle, 1982). Other than the reservoirs (basins) present, the sewage treatment plant could also be a source of contamination. A plan view of the north boundary area of the arsenal is provided in Figure A.13 (Hager and Loven, 1982).

Studies to Determine Remedial Actions

A number of studies have been conducted on containment and treatment options for the ground water underlying the Rocky Mountain Arsenal. Of the many treatment techniques evaluated, activated carbon adsorption was found to be the most cost effective (Hager and Loven, 1982). Testing on dynamic columns of granular activated carbon indicated that diisomethylphosphonate (DIMP) was the first to appear in the effluent of the column. An interim containment and treatment system was installed in 1978, with the location shown in Figure A.13 (Hager and Loven, 1982). A 1,500 foot long containment system consisted of six 12-inch withdrawal wells on 200-foot centers, and twelve 6-inch recharge wells on 100 foot centers. A full-scale granular activated carbon system was also installed. Following treatment the recharge is by gravity feed. Between the dewatering and recharge wells a 2 foot thick bentonite slurry wall, 1500 feet long, was constructed to prevent recirculation of treated waters.

After withdrawal of contaminated ground water from the north boundary area, the water is passed through a dual-media filter to remove


SOUTH
PLATTE
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RESERVOIR A
APPROXIMATE EXTENT
OF CONTAMINATION
SCALE
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Figure A.12: Extent of Ground Water Contamination at Rocky Mountain Arsenal (Shukle, 1982)

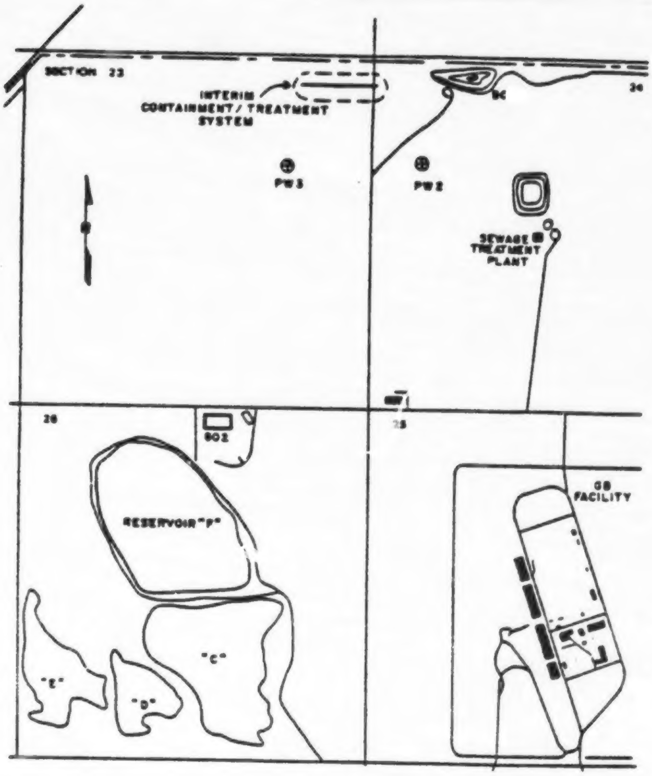

SECTION 23
INTERIM
CONTAINMENT/TREATMENT
SYSTEM
SC
24
PW3
PW2
SEWAGE
TREATMENT
PLANT
26
602
25
RESERVOIR "F"
GB
FACILITY
"C"
"E"
"D"

Figure A.13: North Boundary Area of the Rocky Mountain Arsenal (Hager and Loven, 1982)

suspended matter, then to activated carbon columns, and finally to post filtration prior to recharge. Calgon adsorption equipment was used with monitoring over a three-year period from 1978 to 1981. The principal operating parameter used was a maximum effluent DIMP concentration of 500 μg/l. Carbon was replaced periodically. Some of the salient features of the activated carbon system are listed in Table A.12 (Hager and Loven, 1982). Over the operating period of three years, it was observed that the granular activated carbon adsorption process was effective in removing most organic compounds. The system operated unattended except for periodic monitoring, backwashing and carbon replacement.

While the interim containment and treatment system was being tested, analytical work sponsored by the U.S. Army was in progress. A digital transport model for contamination of ground water at Rocky Mountain Arsenal was developed (Warner, 1979). This model was used to determine the effects on ground water movement, and on DIMP concentrations in ground water, of the bentonite barrier in the aquifer near the north boundary of the arsenal. The ground water flow equation was coupled with a method-of-characteristics solution of the solute-transport equation, and solved by an iterative-alternating-direction-implicit procedure. This transport model assumes steady-state ground water flow and conservative (nonreactive) transient transport of DIMP. In simulations, it was assumed that the bentonite barrier was impermeable and penetrated the entire thickness of the aquifer. It was estimated that the 1,500 foot barrier would intercept about 50% of the DIMP that would otherwise cross the north boundary. Of the ground

Table A.12: Information on Interim Granular Activated Carbon Treatment System (1/7/78 through 6/30/81) Used at North Boundary of Rocky Mountain Arsenal (Hager and Loven, 1982)

Parameter	Information
Adsorption Mode	Single stage fixed bed
Carbon Bed Volume ft^3	666
Flow Rate (gpm)	70-100
Contact Time (minutes)	50-300
Type of Carbon	Calgon Service Carbon
DIMP Concentration	
Influent	1200 μg/1 average
Effluent	non-detectable
Carbon Use Rate	
Projected	0.33 lbs per 1000 gallons
Actual	1.00 lb per 1000 gallons

waters with DIMP concentrations greater than 500 micrograms per liter, 72% would be intercepted by the barrier. It was also found that the amount of DIMP underflow intercepted may be increased to 65% by doubling the pumpage, or to 73% by doubling the length of the barier. The report concludes that the containent of DIMP-contaminated ground water could also be further accomplished by a hydraulic barrier consisting of both withdrawal and recharge wells. The hydraulic barrier could be just as effective as the bentonite barrier, with the only difference being the additional pumping required to account for recirculation between the line of withdrawal wells and recharge wells. The simulation results of this modeling study are summarized in Table A.13 (Warner, 1979).

Remedial Actions Implemented

Following the encouraging results from the interim containment and treatment system, a permanent facility was installed in 1981 to contain the ground water contamination at the north boundary. This facility included a 6700 foot long clay slurry wall which was installed 200 feet inside the arsenal perimeter. Dewatering (withdrawal) and reinjection (recharge) wells which are present along the barrier remove water for treatment and deliver purified water into the aquifer. The 6700 foot long boundary includes the 1500 foot pilot system as well as 29 new alluvial dewatering wells and 38 new discharge wells (Shukle, 1982). There are three separate water collection systems, with different organic compositions in each. Therefore, for treatment flexibility three different adsorption trains were used, rather than treating a mixed influent. This is illustrated in the process diagram in Figure

Table A.13: Simulation Results of a Digital-Transport Modelling Study at Rocky Mountain Arsenal (Warner, 1979)

Model Simulations	Underflow Intercepted by Barrier	DIMP Intercepted by Barrier	Water-level Effects South of the Barrier and on the Arsenal
Simulation 2: 1,500-ft bentonite barrier near D Street.	Barrier would intercept about 0.09 ft^3/s or about 25 percent of the total ground-water underflow.	Barrier would intercept about 50 percent of the total DIMP and about 72 percent of ground water with DIMP concentrations greater than 500 $\mu g/L$.	No significant changes in water-table altitude or in direction and rate of ground-water movement.
Simulation 3: 1,500-ft bentonite barrier near D Street with twice the pumpage and recharge.	Barrier would intercept about 0.18 ft^3/s or about 50 percent of the total ground-water underflow.	Barrier would intercept about 65 percent of the total DIMP and about 90 percent of the ground water with DIMP concentrations greater than 500 $\mu g/L$.	A 1- to 2-ft drawdown in the water-table altitude would occur on the arsenal over most of the model area. The minimum drawdown would be about 5 ft near the barrier and decrease to about 3 ft approximately 1,000 ft south of the barrier.
Simulation 4: Bentonite barrier near D Street extended 1,500 ft to west	Barrier would intercept about 0.10 ft^3/s or about 28 percent of the total ground-water underflow.	Barrier would intercept about 57 percent of the total DIMP.	South of the barrier only minor changes in the water-table altitude would result and a maximum rise of slightly more than 3 ft would occur.
Simulation 5: Bentonite barrier near D Street extended 1,500 ft to east.	Barrier would intercept about 0.18 ft^3/s or about 50 percent of the total ground-water underflow.	Barrier would intercept about 73 percent of the total DIMP.	No significant changes.

Table A.13 (continued)

Water-Level Effects North of the Barrier and Off the Arsenal	DIMP Concentrations of Underflow Across the North Boundary of the Arsenal	DIMP Concentrations of Ground Water Off the Arsenal
No significant changes.	The maximum DIMP concentration of ground-water underflow across the boundary would not be reduced by this barrier configuration. Ground water with DIMP concentrations greater than 500 μg/L would cross the boundary both east and west of the barrier.	A plume of ground water with DIMP concentrations less than 200 μg/L would develop within 4 years after initial operation of the barrier system and would extend 1,500 to 2,000 ft north of the arsenal.
A maximum rise in the water-table altitude of about 8 ft would occur just north of the barrier caused by doubling the recharge.	The barrier would intercept almost all of the ground water with DIMP concentrations greater than 500 μg/L. Doubling the pumpage would result in a faster removal of the DIMP-contaminated ground water from the aquifer and may possibly result in operation of the barrier being discontinued from 2 to 6 years earlier than in simulation 2.	A plume of ground water with DIMP concentrations less than 200 μg/L would develop in approximately 2 years -- one-half the time required in simulation 2.
North of the westward extension of the barrier, a part of the aquifer would become dewatered and a maximum decline of more than 10 ft would occur.	Extension of the barrier to the west would result in an area of ground water with large DIMP concentrations becoming partly trapped in a zone south of the barrier near the bedrock high. This would likely result in a prolonged operating life of the barrier.	Extension of the barrier would prevent any ground-water underflow west of the barrier. Although no new DIMP-contaminated ground water would cross the arsenal boundary, the ground water with already large DIMP concentrations north of the arsenal would remain in place.
No significant changes.	This barrier configuration would prevent any ground water with DIMP concentrations greater than 500 μg/L from crossing the arsenal boundary east of the barrier.	The spread of the plume of ground water with DIMP concentrations less than 200 μg/L that would develop north of the barrier would be greater than for other barrier configurations considered and would be much more effective in reducing DIMP concentrations of ground water off the arsenal.

A.14 (Hager and Loven, 1982). The three adsorbers in parallel are connected to cartridge filters ahead of and following them. There are storage vessels for both fresh and exhausted carbon with two pressure transfer vessels for moving carbon between the equipment in a measured slurry volume. The carbon adsorbers in the permanent facility are up-flow pulsed bed units, whereas the interim plant had down-flow carbon columns which required replacement of all carbon when organic breakthrough occurred. The treatment system characteristics are listed in Table A.14 (Hager and Loven, 1982).

In addition to the north boundary containment and treatment system, the need for a smaller system on the northwest boundary of the property was identified in early 1980 as a result of contamination being found in private wells (Shukle, 1982). The area is a rural residential and agricultural mixture. Subsequent investigation identified a plume containing an organic contaminant at the 1.0 ppb level originating from a railroad yard on arsenal property. The geology was identified as silty sand and clay overlying sand and sandy gravels. The saturated thickness in the area of the system is on the order of 6 to 10 feet, with the alluvium ranging from 50 to 60 feet in thickness. Ground water movement in the area was projected at about 5 feet per day in a northwesterly direction. The control system, called the Irondale system, became operable in December, 1981, and consists of three wells each in two lines for dewatering, and one line of 14 recharge wells. All wells are spaced on 100-foot centers with about 800 feet between rows of dewatering wells and 600 feet between dewatering and recharge wells. The completed system initially encountered flows of 1,600 gpm with

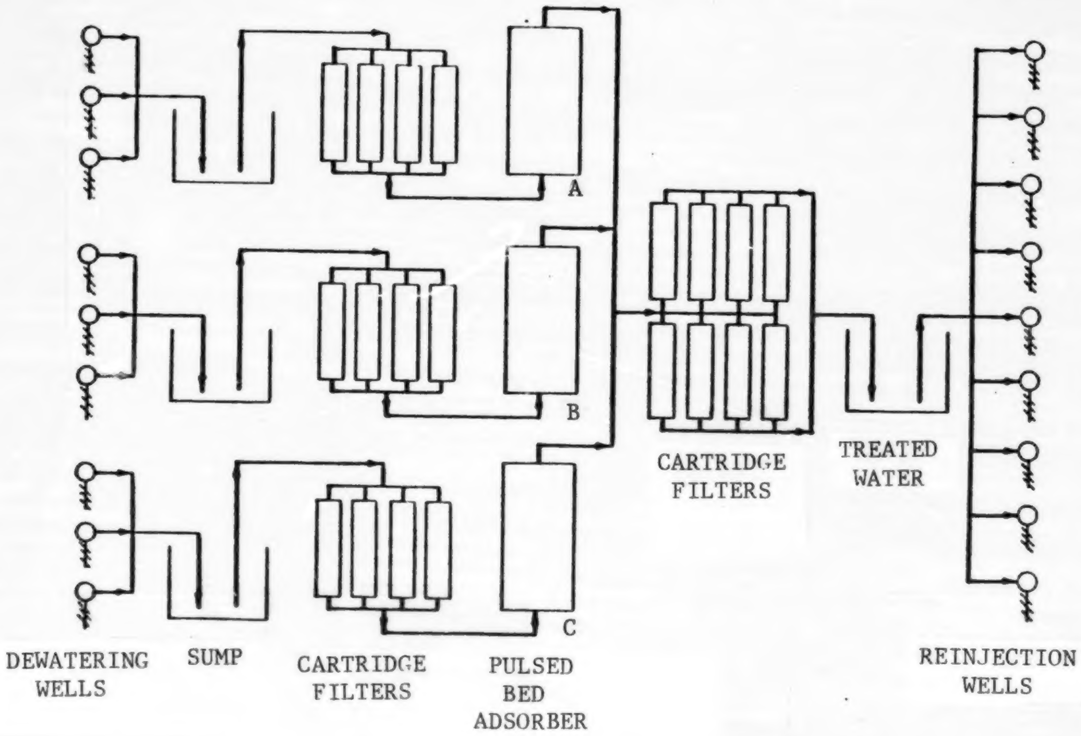

A
B
C
DEWATERING WELLS
SUMP
CARTRIDGE FILTERS
PULSED BED ADSORBER
CARTRIDGE FILTERS
TREATED WATER
REINJECTION WELLS

Figure A.14: Permanent Granular Activated Carbon Treatment Facility at North Boundary of Rocky Mountain Arsenal (Hager and Loven, 1982)

Table A.14: Information on Permanent Granular Activated Carbon Treatment System Used at North Boundary of Rocky Mountain Arsenal (Hager and Loven, 1982)

Parameter	Information
Adsorption Mode	Three pulsed beds operating in parallel
Carbon Bed Volume (each vessel)	1000 ft^3
Volume of Carbon Pulse	70 ft^3
Type of Carbon	WV-G 12 x 40
Design Flow Rate (gpm.)	Average 250/Maximum 350
Contact Time (min.)	Average 84/Minimum 30

Influent Organic Contaminants	Process Stream A	Process Stream B	Process Stream C	Effluent Objectives
DIMP* μg/l	700-1200	100-500	10-100	500
DCPD** μg/l	10-2000	500-2400	24	24
DBCP*** μg/l	1-5	1-5	1-5	0.2

*Diisomethylphosphonate
**Dicyclopentadiene
***Dibromochloropropane

subsequent rates approaching 900 gpm. Piezometric levels existing around the system indicate a very effective hydrological barrier to contaminant migration. Improvement in the quality of downgradient waters has also been observed.

As shown in Figure A.15, the U.S. Army is evaluating a third system to be located between the two existing systems (Shukle, 1982). Subsequent efforts will then be focused on source control which will likely include the disposal basins, the railroad yard, the manufacturing and chemical storage area plus burial sites which over years of use has impacted ground water on the arsenal (Shukle, 1982).

NEW JERSEY DEPARTMENT OF ENVIRONMENTAL PROTECTION AQUIFER RESTORATION PROGRAM

The Ground Water Quality Protection Division in the New Jersey Department of Environmental Protection (NJDEP) was started 6 years ago to address the complaints from the public concerning leaking gasoline storage tanks (Kasabach and Althoff, 1983). Over 300 different contamination problems in the state have been, or are being, investigated by the Division. The success and efficiency of NJDEP in avoiding long and involved legal actions concerning ground water contamination problems can be identified as a combination of the following three factors (Althoff, 1983):

(1) NJDEP has legislated authority to protect the waters of the state. This authority at least requires that pollutors listen to NJDEP and not dismiss them as unable to force action.

(2) A competent staff, which is respected by the companies approached concerning their ground water contamination problems. The companies work to alleviate the problems rather than argue about the validity of claims made against them.

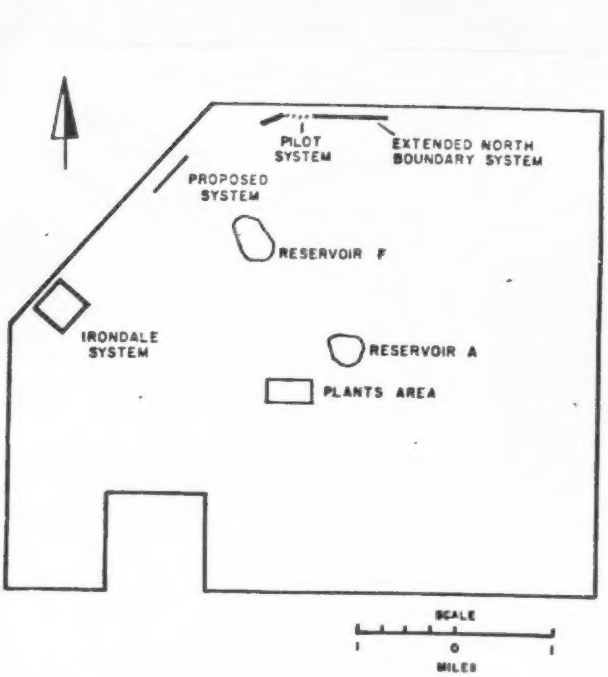

PILOT SYSTEM
EXTENDED NORTH BOUNDARY SYSTEM
PROPOSED SYSTEM
RESERVOIR F
IRONDALE SYSTEM
RESERVOIR A
PLANTS AREA
SCALE
1
0
1
MILES

Figure A.15: Containment System Locations at Rocky Mountain Arsenal (Shukle, 1982)

(3) To avoid a negative public image, companies have moved fast to alleviate their ground water contamination problems.

The sources of ground water contamination in New Jersey have been classified as industrial, hydrocarbon loss, landfills, illegal dumpsites, and miscellaneous. The number of ground water investigations and their categorization is included in Table A.15 (Kasabach and Althoff, 1983). The investigations have also been classified in terms of contaminant types as shown in Table A.16 (Kasabach and Althoff, 1983). A summary of aquifer restoration programs in New Jersey, as of January, 1983, is listed in Table A.17 (Kasabach and Althoff, 1983). Discharge from contaminated wells to sewer systems, for treatment on site or at a local wastewater treatment plant, is an important decontamination option in New Jersey. Hydrocarbon recovery systems have not been included in Table A.17, though they are in use in industry-related clean-up mostly for organic solvents, metals and inorganic contaminants. Hydrocarbon losses to aquifers have been identified to be due to a variety of reasons such as service station contamination of domestic or municipal wells, home heating oil leaks, fuel spills at military installations, and poor housekeeping at railroad yards.

To serve as an illustration of some aquifer restoration efforts in New Jersey, summary information on six industrial case studies is listed as follows by company, pollutant, remedial action, cost, and key issues and comments:

(1) Company: Rockaway Township

Pollutant: trichloroethylene; town's only well field (3 wells) affected.

Table A.15: Ground Water Contamination Investigations in New Jersey -- By Source (Kasabach and Althoff, 1983)

Source	Industrial[1]	Hydrocarbon Loss[2].	Landfill[3]	Illegal Dump Site	Miscellaneous
Number of Investigations	195	52	26	21	14
Per Cent (%) of Total (308)	63	17	8	7	5

[1] Chemical, petrochemical and plating industries predominate.

[2] Includes all types, from major recovery programs at some refineries to service station and home heating oil spills. Some cases involve petroleum contamination on "Industrial" sites.

[3] New Jersey has 300 landfills. The Division of Water Resources investigates selected sites referred to the Division by other agencies.

Table A.16: Ground Water Contamination Investigations in New Jersey -- By Contaminant Type (Kasabach and Althoff, 1983)

Waste Type	Organics[2]	Hydrocarbons[3]	Metals	Inorganics	Radioactive
Number of occurrences[1]	209	61	59	36	4
Per Cent (%) occurrence in ground water cases	68	20	18	12	1

[1] A single ground water investigation often involves more than one contaminant type e.g. plating wastes and cutting oils. Thus, the combined totals exceed caseload of 308 investigations in March 1983.

[2] Volatile organic solvents account for most organics reaching New Jersey aquifers, and of these six to ten compounds dominate the list.

[3] Hydrocarbon clean-ups include removal of floating product and, increasingly, decontamination for dissolved fractions such as benzene, toluene and xylene.

Table A.17: Aquifer Restoration Programs in New Jersey -- January, 1983 (Kasabach and Althoff, 1983)

Treatment Methodology	Discharge to Sewer For Treatment[2] On-Site	Discharge to Sewer For Treatment[2] Off-Site	Aeration[3]	GAC[4]	Aeration Plus GAC	Biological	Misc.
Number of Uses	10	11	7	3	1	1	3
Per Cent (%) of Total Clean-up Programs (36)[1]	28	31	19	8	3	3	8

[1] Includes systems both in operation and under construction. Hydrocarbon recovery programs are not included.

[2] Contaminants are intercepted either by wells or by interceptor trenches. Contaminated production wells are used in some programs for plume control. One decontamination program utilizes both aeration and sewer discharge from seperate wells.

[3] Includes both natural aeration schemes as well as systems engineered to enhance aeration via towers, nozzles and other equipment.

[4] Granular activated carbon.

Remedial Action: Two 20,000 lb GAC units installed at well field.

Cost: Estimated as of Sept., 1981 -- $0.30 million.

Issues and Comments:

Employed aeration prior to GAC -- Were expecting big slug of ethers.

Going to discard GAC because water from air stripping is so clean it picks up organics from GAC.

(2) Company: Mideast Aluminum

Pollutant: 1,1,1 trichloroethane, and others

Remedial Action: Air stripping with recharge via infiltration ponds. Pumping about 104 gpm. Organic levels decreasing.

Cost: Estimated as of Mar., 1984 -- $0.4 million.

Issues and Comments:

Feed varies -- 620 ppb (April 1980) to about 100-250 ppb currently.

Lot of work done to determine ground water flow -- rate and direction -- concern about pollutant moving toward municipal wells.

Legal issue -- Use of chlorinated hydrocarbons violated no statute at the time. Felt a community responsibility to participate in resolution. Wanted to share monitoring costs.

Company also required to line existing lagoons and remove settled solids.

Air stripping is cheaper than GAC by (2-4):1. Also had to get air pollution permit.

(3) Company: Allied Chemical

Pollutant: Chloroform, and carbon tetrachloride

Remedial Action: Program consists of two 200 gpm interceptor wells.

Cost: Estimated as of Sept., 1981 -- $0.25 million

Issues and Comments:

Suspected old buried drums or spill -- magnetometer study showed no drums.

Pump to waste treatment plant, very little reaches surface drainage because both compounds evaporated rapidly upon exposure to air.

(4) Company: American Cyanamid

Pollutant: Host of synthetic organic chemicals resulting from decades of manufacturing activity. Shallow monitor wells near waste lagoons confirmed contaminated ground water. Also have reached bedrock aquifer.

Remedial Action: Several dozen wells in overburden and 8 bedrock monitor wells, large demand of plant prevents off-site migration. Water is withdrawn, used for cooling and treated with other process effluent via large-scale activated carbon before surface water discharge.

Cost: Estimated as of Sept., 1981 -- $0.20 million (probably underestimated; program to continue for several years).

Issues and Comments:

Continue pumping to confine movement and locate and reduce sources within plant.

(5) Company: Saytech (Hexcell)

Pollutant: 1,2 dichloroethane

Remedial Action: Interceptor trench and discharge to sewer.

Cost: Estimated as of Sept., 1981 -- $0.1 million

Issues and Comments:

Trench -- Excavate down to clay (8 ft.), gravel placed in bottom, 3 in. perforated pipe set above bottom, gravel again to 1 ft. above seepage line. Trench slumps badly, requires shoring during construction. Impervious cover installed on top of the stone or gravel to prevent clogging of gravel pore spaces.

Trench will be removed at end of decontamination period and filled with bentonite.

(6) Company: Biocraft

Pollutants: Acetone, methylene, chloride, and butyl alcohol.

Remedial Action: Injection-recovery trench system with biostimulation treatment. Start up in June, 1981.

Cost: Estimated as of Sept., 1981 -- $0.15 million.

Issues and Comments:

Chemical reactions in aquifer. Example -- chlorinated hydrocarbons reacting with naturally occurring organic matter has been proven to be the source of dangerous trihalomethane.

Add air and nutrients to help biodegradation.

CASE STUDIES OF AQUIFER RESTORATION VIA BIOLOGICAL PROCESSES

Based upon a review of published literature and contacts with professionals in the field, 15 case studies involving restoration using biological processes were identified in sufficient detail to allow their summarization. This summary information is presented as follows in accordance with location, company affiliation, background, action taken, and effectiveness. The first six case studies involve the enhancement of natural microbial populations in the subsurface environment; and cases (7) through (12) encompass the addition of adapted microbes to the subsurface environment. Cases (13) through (15) involve the use of biological treatment following withdrawal of polluted ground water.

(1) Location: Ambler, Pennsylvania (Raymond, et al., 1975; Raymond, et al., 1976b; Jamison, et al., 1975; and Jamison, et al., 1976.

Company Affiliation: Sun Ventures, Inc., Marcus Hook, Pennsylvania.

Background: A pipeline break spilled 3,186 barrels of high octane gasoline to the ground water. The aquifer was composed of a highly fractured dolomite that was a very good source of ground water although silt and clay filled many of the fractures. The gasoline was contained by pumping nearby water wells. Physical recovery of the gasoline overlying the water table was begun and continued until no longer productive; an estimated 1000 barrels remained which might take 100 years to recover.

Action Taken: The activity of the gasoline-utilizing microbial population was stimulated by the addition of nitrogen and phosphorus in the form of $(NH_4)_2SO_4$, Na_2HPO_4, NaH_2PO_4, and dissolved oxygen. Dissolved oxygen was supplied by sparging air into wells with diffusers connected to paint sprayer-type compressors. Ground water flow was controlled by a series of injection and withdrawal wells.

Effectiveness: Estimates based on the amount of nitrogen and phosphate retained in the aquifer suggested that from 744 to 944 barrels of gasoline were degraded. The amount of free gasoline in the wells declined as the nutrient addition program continued. The levels of gasoline in the produced water were not reduced during the period of nutrient addition, but no gasoline was found in the produced water ten months later. No direct evidence from the magnitude of conversion of gasoline to bacterial cells in the aquifer was found, although bacterial levels increased greatly. The biostimulation program met its objective of removing the hydrocarbons from the ground waterto the satisfaction of the governmental agency overseeing it.

(2) Location: Millville, New Jersey (Raymond, et al., 1978).

Company Affiliation: Suntech, Inc., Marcus Hook, Pennsylvania.

Background: A gasoline spill from a storage tank was found when gasoline fumes were noticed in basements adjacent to the gasoline station. An undetermined amount of gasoline was lost to the shallow, unconsolidated, sandy aquifer of high porosity and permeability. An extensive clay bed lay beneath the aquifer. Institution of a physical recovery program resulted in the removal of 7000 gallons, but the gasoline recovery rates decreased dramatically after two months to the point where only a few gallons were being recovered daily. The state agency in charge of the cleanup directed the operation to continue recovery operations until no trace of liquid gasoline remained on the ground water surface in order that Millville well field be protected.

Action Taken: A biostimulation program was begun. Nutrients including ammonium sulfate, disodium phosphate, monosodium phosphate, sodium carbonate, calcium chloride-dihydrate, magnesium sulfate-heptahydrate, manganese sulfate-monohydrate, and ferrous sulfate-heptahydrate were added to the wells continuously or in batches. Air was introduced into the wells by a carborundum diffuser with an output of 10 SCFM and by diffusers constructed from DuPont Viaflow® tubing that generated 1 SCFM. Producing wells were used to control ground water flow.

Effectiveness: The biostimulation program was not completely successful; residual gasoline was found at the last sampling period, but no free hydrocarbon was observed in any of the wells after the biostimulation program ended. The gasoline concentrations in cores taken from the aquifer did not seem to change substantially during the biostimulation program. Phenol concentrations decreased to acceptable levels as more aerobic conditions were established in the aquifer. Gasoline levels in the produced water were generally quite low; although following an interruption in the biostimulation program, gasoline was found in the produced water which indicated that pockets of gasoline remained in the aquifer. One well which did not receive nutrients and air was still contaminated with gasoline. This demonstrates that the biostimulation program did have an effect on the degradation of the gasoline. After the area near this well was treated, no free gasoline was found in any of the wells, and operations ceased with state approval. Microbial growth and utilization of nutrients and dissolved oxygen backed up the conclusion that enhanced microbial degradation was responsible for the removal of the gasoline.

(3) Location: Parkside, Pennsylvania (Suntech, 1978).

Company Affiliation: Environmental Group of Suntech, Inc., Marcus Hook, Pennsylvania.

Background: Gasoline fumes from a gas station spill reached the Parkside Elementary School and forced its closure. Physical recovery was able to remove much of the gasoline and to lower the water table so that fumes did not reach the school.

Action Taken: Nutrients and oxygen were supplied to the ground water microorganisms for six months.

Effectiveness: Tests showed that no excess hydrocarbon remained, but no data was presented to judge this claim. The fume problem was alleviated.

(4) Location: LaGrange, Oregon (Minugh, et al., 1983).

Company Affiliations: Environmental Emergency Services Company, Portland, Oregon; Chevron U.S.A., Concord, California; and consultants: Suntech Group, Marcus Hook, Pennsylvania.

Background: Gasoline fumes were detected in the basements of two restaurants and led to their closure. The source of contamination was traced back to a bulk plant storage tank which until recently had been owned by Chevron. A field investigation determined the boundaries of the gasoline plume and the hydrogeologic features of the site. The shallow ground water (about 13 ft) roughly paralleled the land surface and was overlain by a top layer of topsoil, gravel, and silt at the surface; a five foot section of assorted gravel, medium to coarse sand with some clay and silt; and a third layer about 4 ft in thickness which was composed of medium to large cobbles, gravel, and coarse sand. A number of stream channel deposits crossed the site and provided highly permeable pathways for ground water flow.

Action Taken: Laboratory biostimulation studies showed that the following nutrients were needed to stimulate the microbial population to degrade the gasoline: ammonium chloride, sodium phosphates, iron, manganese, magnesium, and calcium. A system was designed to draw down the static water levels 6 to 10 ft, to recycle the produced water (thereby recycling nutrients and eliminating the problem of disposing of the water), and to supply nutrients and dissolved oxygen to the microbes. Ground water was cycled through the site by installing three recovery wells in highly contaminated areas and injecting produced water into trenches upgradient of the area of known contamination. Air was supplied through a two-inch line at the bottom of the injector trench with porous stone diffusers every 40 ft.

Effectiveness: The physical recovery system accounted for recovery of 3,266 gallons of free hydrocarbon. Nutrients broke through the production wells after only a few days, but high dissolved oxygen levels did not reach the recovery wells for five months due to its removal by microorganisms. Bacterial levels increased up to six million times the initial levels. The system was operated for a year to encompass the complete range of seasonal water fluctuations. After nine months of treatment, soils in the highly contaminated tank storage area still showed signs of gasoline contamination at levels of 500 to 100 ppm and the average concentrations of dissolved carbon (DOC) was 20 ppm. After the biostimulation program ended the DOC in the water had fallen to the point where 71 percent of the measurements fell below 5 ppm and 50 percent were under 2 ppm. Since the DOC levels initially were not given, it is difficult to evaluate the efficiency of the cleanup. Free product was no longer present in the recovery or monitoring wells, and the vapor problems at the restaurants were mitigated. The cleanup effort was ended with the establishment of an appropriate ground water monitoring program.

(5) Location: Waldwick, New Jersey (Jhaveri and Mazzacca, 1982).

Company Affiliation: Ground Water Decontamination Systems, Waldwick, NJ; Consultants: Suntech, Inc., Marcus Hook, PA; Geraghty and Miller, Syosset, NY; and Princeton Aqua Science, New Brunswick, NY.

Background: An estimated 33,000 gallons of a mixture of methylene chloride, acetone, n-butyl alcohol, and dimethylanaline was spilled at the Biocraft Laboratories, Inc. pharmaceutical manufacturing plant in Waldwick, NJ. The contamination was first detected in a small stream into which the storm sewers from Biocraft discharged. Following the installation of several monitoring wells at the Biocraft site, a monitoring program revealed that the ground water was contaminated and was the source of the pollution in the storm sewers. The contamination problem was confined to an 8 to 15 ft layer of glacial till composed of a poorly sorted mixture of boulders, cobbles, pebbles, sand, silt, and some clay. A 40 foot thick semi-consolidated layer of silt and fine sand lay below the glacial deposit and acted as an aquitard to separate the shallow aquifer from a shale layer which served as the drinking water supply for much of the region. Ground water movement was fairly rapid at 0.4 ft per day in the shallow water table. The permeability of the glacial till varied from 1 to 35 gpd per ft^2.

Action Taken: An average of 10,000 gallons of contaminated ground water was collected per month and sent to an approved disposal facility. Other options were investigated; a series of biodegradation indicated that the native microbial population could be stimulated to degrade the contaminants. A hydrogeological survey was performed so that a system to confine the contaminated ground water on site and decontaminate it could be designed. The biostimulation-decontamination system which was designed consisted of a trench and series of wells to withdraw the ground water, four tank wagons used in the biostimulation process, two re-injection trenches, and nine wells to inject air from the blower into the aquifer. The contaminated water was pumped from the dewatering system into two of the tank wagons. In these stirred activating tanks, air was supplied at 50 SCFM, nutrients added as needed, and the temperature maintained at 18 to 22°C. Following a residence time of 16 to 18 hours in the activating tank, the effluent was pumped to the two settling tanks. About 200 gallons of the activated sludge slurry was recycled to the activating tanks daily. The effluent from the settling tanks which was enriched with organisms, nutrients, and some oxygen was supplied with additional oxygen and recirculated via the re-injection trenches. Nine wells provided air to the ground water as it flowed from the re-injection trench to the dewatering system. The following compounds were used in the nutrient solution: 500 mg/l NH_3Cl_2, 270 mg/l KH_2PO_4, 410 mg/l K_2HPO_4, 18 mg/l $MgSO_4$, 9 mg/l Na_2CO_3, 0.9 mg/l $CaCl_2$, 18 mg/l $MnSO_4$, and 0.45 mg/l $FeSO_4$. An excess of several nutrients was added initially and the nutrient solution was adjusted to contain 44 mg/l KH_2PO_4, 15 mg/l K_2HPO_4, 18 mg/l $MgSO_4$, 9 mg/l Na_2CO_3, 1.8 mg/l $MnSO_4$, 0.45 mg/l $FeSO_4$, and 0.9 mg/l $CaCO_3$. The system treated 10,000 gallons per day with a 9.5 gpm feed stock flow and retention time in the activating tank of 17.5 hours.

Effectiveness: The above ground system was able to remove about 95% of the organics, but some of this may have been due to air stripping the volatile organics instead of microbial activity. The contaminant levels in one of the pumping wells declined from an average of 91 ppm methylene chloride and 54 ppm acetone to less than 1 ppm within a year of treatment. The COD of the ground water from the pumping well was significantly reduced also. The area near the pumping wells was the last to be treated and still showed fairly high levels of contamination (up to 40 mg/l of methylene chloride), but the monitoring wells closer to the re-injection system had very low levels of methylene chloride; a reduction from about 70 ppm to less than 0.02 ppm was noted for two of the monitoring wells. A separate investigation showed that the acclimated organisms from the site were able to biodegrade methylene chloride.

(6) Location: Karlsruhe, West Germany (Nagel, et al., 1982).

Company Affiliation: Federal Ministry for Research and Technology.

Background: A number of spills and losses during transfers had contaminated the train yard of the German Railroad System in Karlsruhe with petroleum products. The hydrocarbons reached the ground water table and caused a nearby water well to be closed. Cyanide was also found in the ground water. The aquifer was composed of coarse sands and gravel mixed with pebbles and had a permeability factor of 2.1×10^{-3} m/s.

Action Taken: A system was constructed in which contaminated ground water was pumped out, treated with ozone, and then reinfiltrated via five injection wells. This treatment system controlled ground water flow, improved the biodegradability of the contaminants, and provided oxygen to increase the activity of the microorganisms in the aquifer. Approximately 1 g of O_3 per g of DOC was added to the ground water and allowed a four minute contact time. The oxygen content increased to 9 mg/l with a residual 0.1 to 0.2 g of ozone/m^3 in the treated water.

Effectiveness: This treatment was effective in restoring the aquifer. Dissolved oxygen levels increased in the wells with the most rapid changes noted in the monitoring wells closest to the infiltration wells. Oxygen consumption in the heavily contaminated zone reached 40 kg/day, but began to decline as the DOC levels dropped. The DOC concentrations fell to about 1.5 g/m^3 and virtually no mineral oil hydrocarbons or cyanide was detected. Total bacterial counts increased about tenfold, but potentially harmful bacteria did not increase. The aquifer was restored to the point where drinking quality water was produced. The destruction of the hydrocarbons by ozone may have been more important in the cleanup than microbial activity. Microbial activity within the aquifer may have been limited since ozone is a toxicant (it is used as a disinfectant in some water distribution systems) and levels of inorganic nutrients were not supplemented.

(7) Location: Indiana (Polybac Corporation, 1983).

Company Affiliation: Polybac Corporation, Allentown, PA.

Background: An acrylonitrile spill contaminated the soil and ground water of a site in Indiana.

Action Taken: Treatment was by pumping ground water from several wells to a bio-treator seeded with mutant bacteria from polybac and then injection into the ground water table.

Effectiveness: The concentrations of acrylonitrile fell from 100 to 1 ppm within three months. The report did not contain sufficient details to judge the importance of microbial activity in the removal of the acrylonitrile.

(8) Location: Midwest Metropolitan Area (Walton and Dobbs, 1980).

Company Affiliation: Polybac Corporation, Allentown, PA.

Background: The ground water beneath a rail yard was contaminated by a leaking rail car which released about 7000 gallons of acrylonitrile. The aquifer contained significant amount of silt and clay and consequently had a low permeability. The ground water table was quite shallow -- only about 5 ft.

Action Taken: The ground water was treated by air stripping the recovered ground water and, after concentrations had been reduced enough to allow microbial growth, by adding mutant bacteria.

Effectiveness: The degradation of acrylonitrile occurred rapidly, as the levels fell from 1000 ppm to the limits of detection within a month. No data was presented that conclusively linked the drop in the concentration of acrylonitrile to microbial activity by the mutant bacteria.

(9) Location: Central Michigan (Walton and Dobbs, 1980).

Company Affiliation: Polybac Corporation, Allentown, PA.

Background: A mixture of phenol and its chlorinated derivatives was spilled and reached the ground water.

Action Taken: Activated carbon filters were used to reduce the high concentrations of pollutants to levels tolerable by microbes. Mutant bacteria were injected into the soil and a surface runoff containment pond to degrade the pollutants.

Effectiveness: Degradation of phenol was rapid, but slower for o-chlorophenol. Once again the absence of carefully controlled experiments prevented any firm conclusions on the role of the mutant bacteria, although the data suggested that there was a correlation between the removal of the contaminants and the introduction of microbes.

(10) Location: Midwest (Quince and Gardner, 1982a and 1982b).

Company Affiliation: O.H. Materials, Findlay, OH.

Background: A transportation accident spilled more than 100,000 gallons of various organic compounds including ethylene glycol and propyl acetate over a 250,000 sq ft area. Three of the compounds penetrated the soil rapidly and were not removed when the contaminated surface soils were excavated. The soil consisted of a thick silty clay that extended to a depth of 50 ft. The water table was quite shallow and most of the contaminants were confined within it at a depth of 6 to 10 ft.

Action Taken: A series of 200 recovery wells were installed and the ground water pumped to a treatment system employing clarification, aeration, and granular activated carbon adsorption. Once levels of the contaminants fell below 200 ppm, a biostimulation program was begun using special bacteria, nutrients, and air which were injected into the surface.

Effectiveness: The system was able to reduce the concentrations of ethylene glycol from 1200 mg/l and propyl acetate from 500 mg/l to less than 50 mg/l and the total concentrations of spilled compounds from 36,000 to less than 100 mg/l. After the treatment had reduced the concentration of the contaminants to levels acceptable to the regulatory agencies overseeing the treatment, a further monitoring program revealed that the contaminants were below detectable limits. The importance of the microbes in the removal of the contaminants cannot be judged, although the authors noted that the inoculation and biostimulation program reduced the time necessary to reach the contaminant levels that met the regulatory agencies' approval.

(11) Location: Unknown (Quince and Gardner, 1982a and 1982b).

Company Affiliation: O.H. Materials, Findlay, OH.

Background: Ground water contamination which resulted from leaks, overfills, and spillage at an industrial facility included dichlorobenzene, methylene chloride, and trichloroethane at levels up to 2,500 mg/l. The site geology consisted of a fractured limestone bedrock overlain by weathered glacial deposits.

Action Taken: The primary treatment was air stripping. The treated water was inoculated with a commercial hydrocarbon degrading bacteria and nutrients and injected into the subsurface.

Effectiveness: The levels of bacteria increased until optimum conditions were established in the reactor and then were injected into the soil. With 2½ months, the levels of methylene chloride fell from 2,500 mg/l to less than 100 mg/l and dichlorobenzene fell from 800 mg/l to less than 50 mg/l in a monitoring well. The inoculated bacteria were expected to continue to degrade the contaminants beyond the 95% reduction reached before the treatment was terminated. The importance of microbial activity could not be determined from the data presented.

(12) Location: Unknown (Ohneck and Gardner, 1982).

Company Affiliation: O.H. Materials, Findlay, OH.

Background: An accidental spill of 130,000 gallons of organic chemicals entered a 15 ft thick shallow unconfined aquifer and produced contaminant levels as high as 10,000 ppm. A 50 to 60 ft thick gray silty clay separated the permeable aquifer from the main aquifer which was a major source of drinking water.

Action Taken: A treatment system employing clarification, granular activated carbon adsorption, air stripping, and reinjection was assembled. An investigation into stimulating microbial activity showed that the contaminants were biodegradable at concentrations below 1000 ppm. Both the indigenous microflora and a specific facultative hydrocarbon degrader were able to biodegrade the materials in a soil/water matrix rapidly when supplied with nutrients. A biodegradation program was initiated that inoculated the treated water with the specific hydrocarbon degraders, nutrients, and oxygen.

Effectiveness: Microbial growth responded positively to the presence of additional nutrients. The biological treatment process accelerated the removal of the compounds as shown by a series of soil borings during the treatment process and reduced the levels of contaminants in the ground water to less than 1 ppm. The specific hydrocarbon degraders did not increase degradation in laboratory tests beyond that of the native microbes and may not have significantly increased *in situ* biodegradation. No data was presented that showed that the number of the specific hydrocarbon degraders increased in the subsurface or that they were able to outcompete the indigenous microflora in degrading contaminants.

(13) Location: Mapleton, Illinois (Lindorff and Cartwright, 1977).

Company Affiliation: Illinois State Geological Survey, Urbana, IL.

Background: A train derailment spilled 20,000 gallons of acrylonitrile which contaminated nearby soil and ground water and affected several drinking water wells.

Action Taken: Sixteen monitoring wells were installed at the site and five showed contamination. The contaminated ground water was withdrawn and sent to a sewage treatment plant for treatment. Five to 8 ft of contaminated soil was also excavated and taken to a landfill for disposal.

Effectiveness: Ground water quality improved to the point where the case was closed. The effectiveness of the sewage treatment process was not discussed.

(14) Location: Leon, Kentucky (Wentsel, et al., 1981).

Company Affiliation: Atlantic Research Corporation, Alexandria, VA; Consultant, O.H. Materials, Findlay, OH.

Background: Four railroad tank cars derailed near Leon, Kentucky, spilling 390,000 liters of acrylonitrile. About one-third of this was recovered, and much of the remainder was burned or lost to the soil or a nearby river. The area had soils of a Muskingreen-Montivalle-Ramsey association.

Action Taken: O.H. Materials was hired as a consultant for the cleanup and installed 16 aeration ponds to treat the contaminated water. The treated water was then injected into the soil. When the concentrations of acrylonitrile fell below 3 ppb, the water was released to the nearby river.

Effectiveness: The treatment process reduced the levels of acrylonitrile to less than 3 ppb, but the importance of biological activity was not estimated.

(15) Location: Ott/Storey site in Muskegon, Michigan (Shuckrow and Pajak, 1981 and 1982).

Company Affiliation: Michael Baker, Jr., Inc., Beaver, PA.

Background: The ground water at Ott/Story site is contaminted with a variety of volatile organics, phenols, aromatics, and other compounds at levels up to hundreds of mg/l and has a TOC that ranges from 600 to 1500 mg/l.

Effectiveness: Activated sludge cultures could not be acclimated to the ground water even with the addition of nutrients and trace elements and adjustment of the pH or the addition of 10,000 mg/l powdered activated carbon. A commercial microbial culture was also ineffective. Coupling aerobic activated sludge with granular activated carbon adsorption (GAC) was effective in removing 95% of the TOC when the GAC worked effectively, but as GAC removal efficiency declined, so did the overall treatment effectiveness. The levels of most of the organic priority pollutants were also removed to below the limit of detection (0.01 mg/l). Some of the removal in the activated sludge process was due to air stripping, but microbial activity accounted for a large portion. The combination of GAC and activated sludge did not work well for ground water from a less contaminated well having a TOC of only 200-300 mg/1.

SELECTED REFERENCES

Hager, D.G. and Loven, C.G., "Operating Experiences in the Containment and Purification of Groundwater at the Rocky Mountain Arsenal", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1982, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 259-261.

Hittman Associates, Inc., "Surface and Ground Water Contamination from Abandoned Lead-Zinc Mines, Picher Mining District, Ottawa County, Oklahoma", Oct. 1981, Oklahoma Water Resources Board, Oklahoma City, Oklahoma.

Jamison, V.W., Raymond, R.L. and Hudson, J.O., Jr., "Biodegradation of High-Octane Gasoline in Groundwater", Developments in Industrial Microbiology, 1975, Vol. 16, pp. 305-311.

Jamison, V.W., Raymond, R.L. and Hudson, J.O., Jr., "Biodegradation of High Octane Gasoline", In J.M. Sharpley and A.M. Kaplan, ed., Proceedings of Third International Biodegradation Symposium, Applied Science Publishers, 1976, pp. 187-196.

Jhaveria, V. and Mazzacca, A.J., "Bioreclamation of Ground and Groundwater by the GDS Process", Groundwater Decontamination Systems, Inc., Waldwick, New Jersey, 1982.

Kasabach, N. and Althoff, W.F., personal communication, April 1983.

Knox, R.C., Stover, E.L. and Kincannon, D.F., "Examples of Aquifer Restoration", Proceedings of the Ninth Annual Conference of the Groundwater Management Districts Association, 1982, Scottsdale, Arizona, pp. 145-163.

Lindorff, D.E. and Cartwright, K., "Ground Water Contamination: Problems and Remedial Action", Environmental Geology Notes, May 1977, No. 81, Illinois State Geological Survey, Urbana, Illinois.

Minugh, E.M., et al., "A Case History: Cleanup of a Subsurface Leak of Refined Product", Proceedings of 1983 Oil Spill Conference: Prevention, Behavior, Control and Cleanup, San Antonio, Texas, Feb. 28-Mar. 3, 1983, pp. 397-403.

Nagel, G., et al., "Sanitation of Ground Water by Infiltration of Ozone Treated Water", GWF-Wasser/Abwasser, 1982, Vol. 123, pp. 399-407.

Ohneck, R.J. and Gardner, G.L., "Restoration of an Aquifer Contaminated by an Accidental Spill of Organic Chemicals", Ground Water Monitoring Review, Fall 1982, Reprint.

Polybac Corporation, Product Information Packet, Allentown, Pennsylvania, 1983.

Quince, J.R. and Gardner, G.L., "Recovery and Treatment of Contaminated Ground Water: Part 1", Ground Water Monitoring Review, Fall 1982a, Reprint.

Quince, J.R. and Gardner, G.L., "Recovery and Treatment of Contaminated Ground Water: Part 2", Ground Water Monitoring Review, Fall 1982b, Reprint.

Raymond, R.L., Jamison, V.W. and Hudson, J.O., "Final Report on Beneficial Stimulation of Bacterial Activity in Ground Waters Containing Petroleum Products", Committee on Environmental Affairs, American Petroleum Institute, Washington, D.C., 1975a.

Raymond, R.L., Jamison, V.W., and Hudson, J.O., "Beneficial Stimulation of Bacterial Activity in Ground Waters Containing Petroleum Products", AIChE Symposium Series, 1976b, Vol. 73, pp. 390-404.

Raymond, R.L., et al., "Field Application of Subsurface Biodegradation of Gasoline in a Sand Formation -- Final Report", American Petroleum Project No. 307-77, 1978.

Roy F. Weston, Inc., "Sylvester Hazardous Waste Dump Site Containment and Cleanup Assessment", Final Report Prepared for New Hampshire Water Supply and Pollution Control Commission, 1982.

Shuckrow, A.J. and Pajak, A.P., "Bench Scale Assessment of Concentration Technologies for Hazardous Aqueous Waste Treatment", In S.W. Shultz, ed., Proceedings, Land Disposal of Hazardous Waste, Philadelphia, Pennsylvania, Mar. 16-18, 1981, EPA-600/9-81-002b, U.S. Environmental Protection Agency, Cincinnati, Ohio, pp. 341-351.

Shuckrow, A.J. and Pajak, A.P., "Studies on Leachate and Groundwater Treatment at Three Problem Sites", In D.W. Shultz and D. Black, ed., Proceedings, Land Disposal of Hazardous Waste, Ft. Mitchell, Kentucky, Mar. 8-10, 1982, EPA-600/9-82-002, U.S. Environmental Protection Agency, Cincinnati, Ohio, pp. 346-359.

Shukle, R.J., "Rocky Mountain Arsenal Ground Water Reclamation Program", Proceedings of the Second National Symposium on Aquifer Restoration and Ground Water Monitoring, May 26-28, 1982, pp. 366-368.

Stover, E.L. and Kincannon, D.F., "Treatability Studies for Aquifer Restoration", Presented at the 1982 Joint Annual Conference, Southwest and Texas Sections of America Water Works Association, Oct. 1982, Oklahoma City, Oklahoma.

Suntech Group, "Vapors Invade School; Bioreclamation Process Cleans Up Groundwater, Microorganisms Devour Spilled Hydrocarbons", Petroleum Marketer, July-Aug. 1978, Reprint.

Walton, G.C. and Dobbs, G., "Biodegradation of Hazardous Materials in Spill Situations", Proceedings, 1980 National Conference on Control of Hazardous Material Spills, 1980, Louisville, Kentucky, pp. 23-29.

Warner, J.W., "Digital-transport Model Study of Diisopropyl-Methylposphonate (DIMP) Groundwater Contamination at the Rocky Mountain Arsenal, Colorado", U.S. Geological Survey, Denver, Colorado, 1979.

Wentsel, R.S., et al., "Restoring Hazardous Spill-Damaged Areas. Technique Identification/Assessment. Final Report", EPA-600/2-7-81-1-208, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1981.

APPENDIX B

CONSIDERATIONS RELATED TO AQUIFER RESTORATION INFORMATION CENTER

INTRODUCTION

First hand experience gained in this study in searching for aquifer restoration information has demonstrated the minimal amount of relevant information as well as a reluctance on the part of industry to reveal information. In addition, extant information is often associated with litigation and is thus not available to practitioners.

Since aquifer restoration strategies are always time-consuming and costly it is important that a method of locating, assimilating and dissemination of appropriate data/information be developed and implemented. The significance of the prevailing data/information gap becomes more obvious with each new aquifer pollution situation revealed. Consequently, the demand for such information has been accelerating for several years.

Although the basic and associated problems of aquifer contamination are recognized, they are not fully understood as witnessed the many conflicting technical studies as well as exaggerated media attention. Innumerable situations have been and are being studied but to date published literature with significant factual and practical data/information on aquifer restoration design and effectiveness is sparse, although this is beginning to change. The change is stemming from socio-political pressures. Many seminars and workshops are being conducted and the communications gap is being bridged. Solutions and/or mitigation of the problems have been lacking although attempts and proposed approaches toward solving the problems are being presented in the many workshops and seminars currently being held on the subject. This appendix has been prepared to examine the framework and potential usage of an Aquifer Restoration Information Center to bridge the information gap for practitioners in the field.

CONCEPTUAL FRAMEWORK FOR AQUIFER RESTORATION INFORMATION CENTER

An Aquifer Restoration Information Center (ARIC) should be organized on a service bureau concept as illustrated by the conceptual frameworks in Figures B.1 and B.2. Figure B.3 shows the overall data/information flow involving ARIC and its users. The Center will collect, store, assimilate, and disseminate data/information for users of information concerning all aspects of aquifer restoration. Initially these potential users can be broadly classified as including but not limited to:

- Consultants/industry/business/contractors/associations
- University and industry researchers
- Educational institutions
- Media
- Government/legislators
- General public

Currently, the data/information input types can be identified as including, but not limited to:

- Data sources
- Data exchange services
- Machine accessible data systems
- Data requirements for aquifer restoration
- Design, cost, and performance information
- Site information related to aquifer restoration

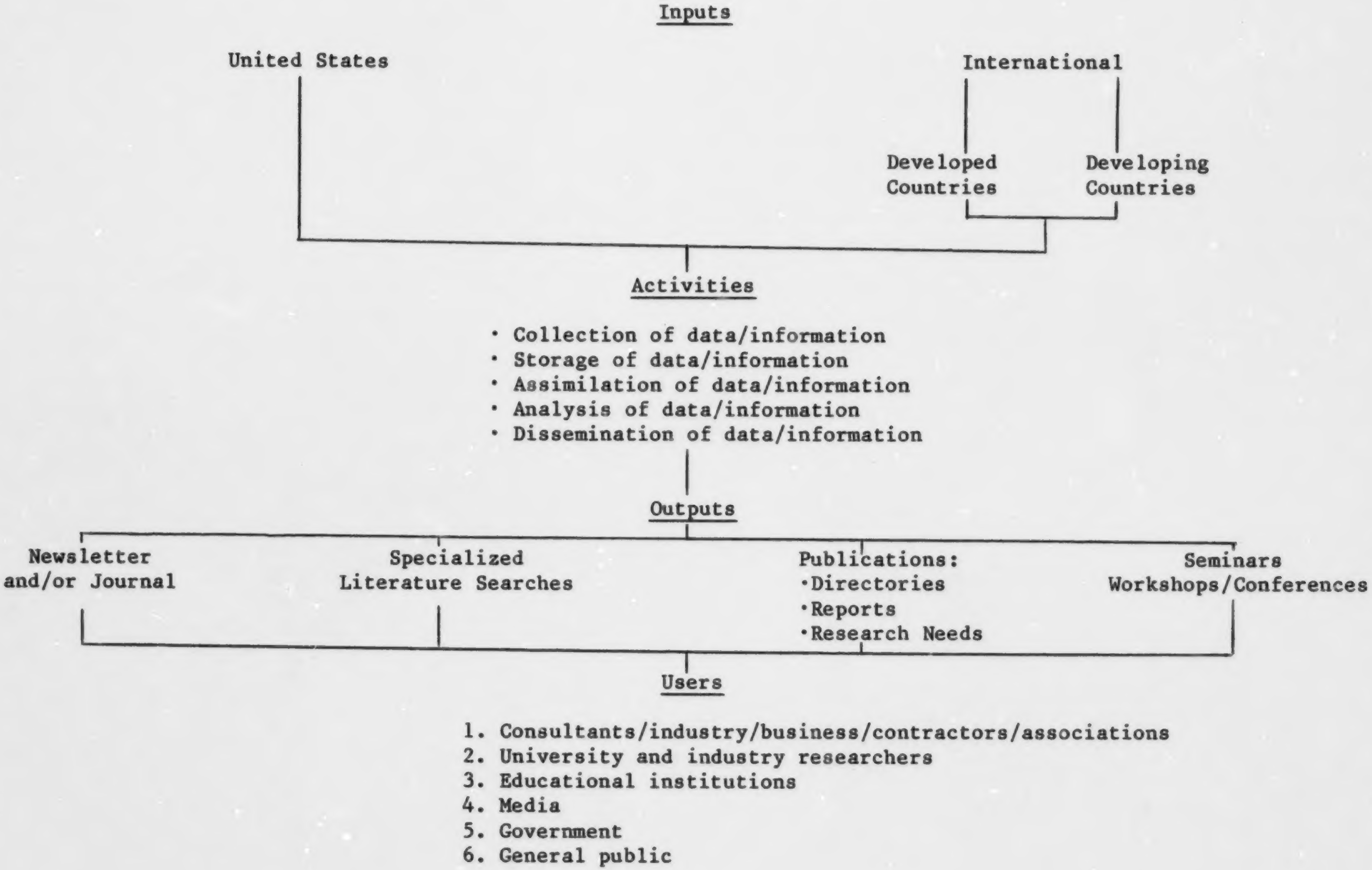

Inputs
United States
International
Developed Countries
Developing Countries
Activities
• Collection of data/information
• Storage of data/information
• Assimilation of data/information
• Analysis of data/information
• Dissemination of data/information
Outputs
Newsletter and/or Journal
Specialized Literature Searches
Publications:
•Directories
•Reports
•Research Needs
Seminars Workshops/Conferences
Users
1. Consultants/industry/business/contractors/associations
2. University and industry researchers
3. Educational institutions
4. Media
5. Government
6. General public

Figure B.1: Conceptual Framework for Aquifer Restoration Information Center (ARIC)

Outputs	Delivery Mechanisms / User Extent and Type	High Users .University/Industry Research .Government .Associations	Medium Users .Consultants .Business .Industry/Contractors .Associations	Low Users .Legislators .General Public .Media .Educational Institutions
Data Base	1. Manual	X	X	
	2. Automated	X	X	
Research and Development	1. Guide to R and D		X	X
	2. Technical Publications	X	X	
	3. Research Inventory (State of Art, etc.)	X	X	
	4. Journal Articles	X	X	
	5. Guidelines "How to do it" Publications		X	
Education	1. Seminars/ Conferences	X	X	X
	2. Workshops		X	X
	3. Short Courses		X	X
	4. University Courses	X	X	
Public Awareness	1. Directories of Resource Persons	X	X	X
	2. Speakers	X	X	X
	3. Product/Process Information	X	X	X
	4. Newsletters			
	a. Research	X		
	b. Applied		X	X

Figure B.2: Conceptual Framework for Information/Technology Transfer Program

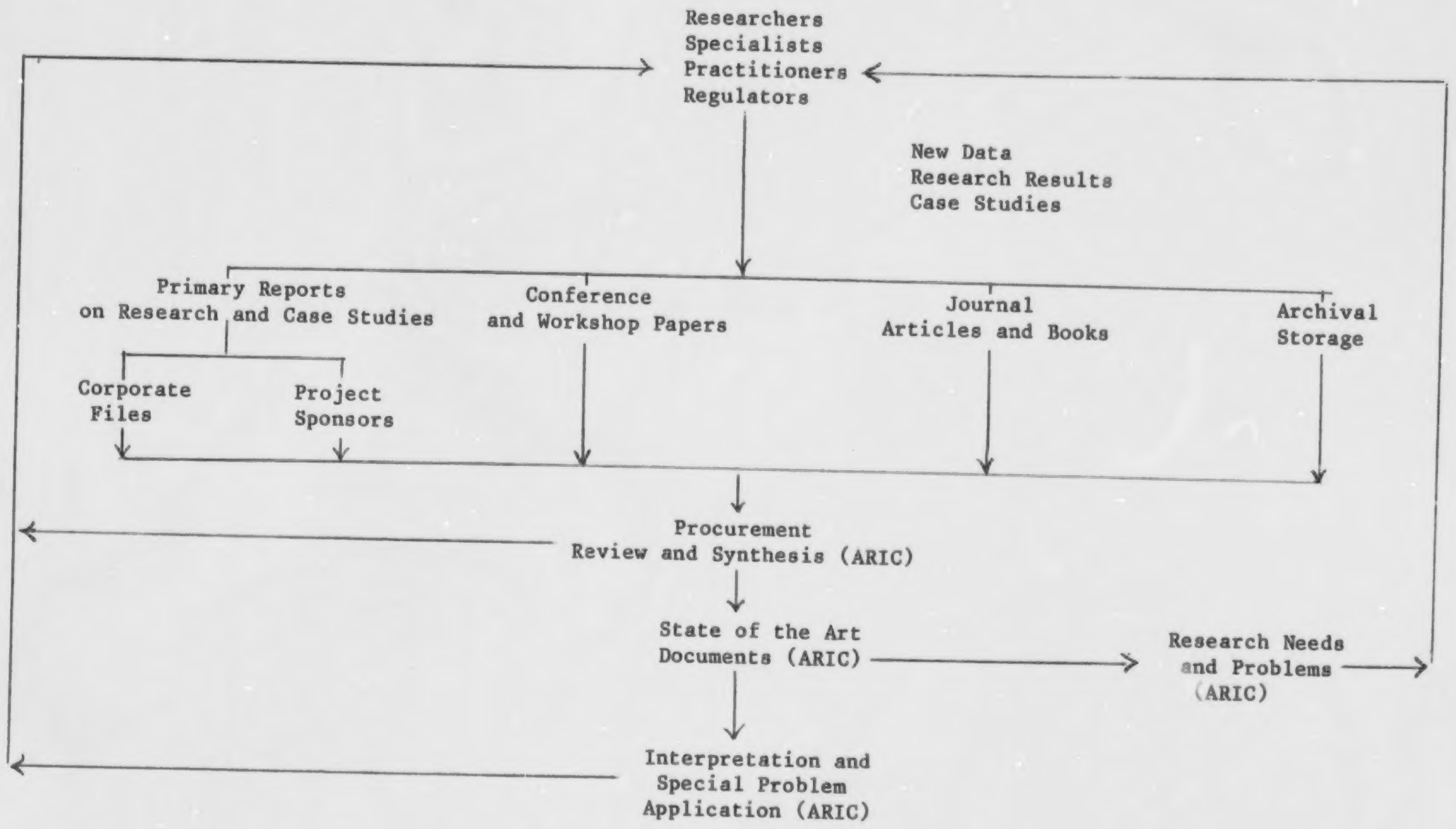

Researchers
Specialists
Practitioners
Regulators
New Data
Research Results
Case Studies
Primary Reports
on Research and Case Studies
Conference
and Workshop Papers
Journal
Articles and Books
Archival
Storage
Corporate
Files
Project
Sponsors
Procurement
Review and Synthesis (ARIC)
State of the Art
Documents (ARIC)
Research Needs
and Problems
(ARIC)
Interpretation and
Special Problem
Application (ARIC)

Figure B.3: Data/Information Flow Involving ARIC

- Case histories of aquifer restoration
- People who can serve as technical experts
- Manufacturers/equipment/services, etc.

The dissemination (information/technology transfer) delivery mechanisms would include:

- Publications (newsletters; directories; reports)
- Specialized literature searches
- Seminars/workshops/conferences

ARIC should operate as a non-political entity to ensure the integrity of its operations. Integral to this concept are provisions for handling proprietary information, avoidance of indiscriminate data/information collection, and duplication of information/data bases or activities.

SUMMARY

The ARIC concept as an information and technology transfer activity holds tremendous potential to satisfy the growing demands throughout the world for reliable information about the varied complexities of aquifer restoration. There is no question that there is a pressing need for ARIC, and this need is expected to considerably increase in the coming years. The critical issue is associated with start-up and base funding for ARIC. Start-up funding of $100,000 would enable the establishment and initial networking of ARIC. Base funding of $50,000 per year would underwrite the basic operations of ARIC. The services to be provided by ARIC should be established on a cost-reimbursable basis.

APPENDIX C

AIR STRIPPING OF VOLATILE ORGANICS FROM GROUND WATER

INTRODUCTION

Stripping is a mass transfer process in which a solute from a solution is absorbed into a gas stream. Hence absorption or desorption is the unit chemical process under consideration. More simply, it is an inter-phase (gas and liquid, here) mass transfer process. Usually, an inert gas is to be used in a stripping operation. Air is inexpensive, containing 78% nitrogen, and can be considered "inert". Air stripping, also known as aeration, has been traditionally used in water and wastewater treatment for removal of gases such as hydrogen sulfide and ammonia, and also for oxygen transfer into the water (Eckenfelder, 1966; and Schroeder, 1977). Interest in air-stripping of volatile organics from water has existed for some time (Thibodeaux, 1974), and has been increasing recently (Thibodeaux and Millican, 1977; Kavanaugh and Trussel, 1980; and Stover, 1982).

For removal of volatile organic contaminants from water, contaminant-free air is continuously contacted with it. Due to a concentration difference the volatile organics get transferred from water to air across the interface. This transfer can occur until an equilibrium is attained in both the phases. In a continuous contacting process, since air is continuously replaced, the majority of the volatile organics should be removed. This is, in essence, the air stripping process.

Among the equipment used is diffused aeration equipment, which is also extensively used for oxygen transfer (Eckenfelder, 1966). A counter-current film flow process is popular for removal of ammonia (Schroeder, 1977), and could possibly be used for volatile organics but will not be considered herein. The best and most efficient air stripping process for volatile organics involves the use of packed tower aeration (Kavanaugh and Trussel, 1980; and Thibodeaux and Millican, 1977). An important design consideration is the desorption rate of the volatile organics into air. Also included herein is a brief review of the theory of mass transfer, design considerations, a case study on removing volatile organics from ground water, and finally, mention of the consequential air pollution concerns.

MASS TRANSFER PROCESS: THEORY

In air-stripping of volatile organics from water, mass-transfer occurs across the interface of two phases; namely the gas (air) phase and the liquid (water) phase. Since it is a diffusional process, the rate of diffusion (N_A) of a species A can be expressed by Fick's law as (Perry, and Chilton, 1973):

$$N_A = - D_v \frac{\delta c}{\delta y} \qquad (1)$$

where

D_v = Diffusivity

$\frac{\delta c}{\delta y}$ = concentration gradient perpendicular to the interface

If it is assumed that equilibrium exists across the interface, then the rates of diffusion in each phase can be equated. Thus,

$$N_A = (- D_g \frac{\delta p}{\delta y}) = (- D_L \frac{\delta c}{\delta y}) = \qquad (2)$$

where

D_g = diffusivity in the gas phase

$\frac{\delta p}{\delta y}$ = pressure gradient perpendicular to the interface

D_L = diffusivity

This can also be expressed as

$$N_A = k_L a\ (c - c_s) = k_g a\ (p - p_g) = K_L a\ (c^* - c) \qquad (3)$$

where

k_L = liquid phase mass transfer coefficient,

k_g = gas phase mass transfer coefficient,

K_L = overall liquid phase mass transfer coefficient (m/s),

a = interfacial area (m^2/m^3), and

c^* = liquid phase equilibrium concentration of species A.

c = liquid phase concentration of species A

Figure C.1 shows the interface mass transfer process. Now from Henry's law, the equilibrium concentration of a species (c_s) is defined as (Eckenfelder, 1966):

$$C_s = H\ p \qquad (4)$$

where

H = Henry's constant

p = pressure

Therefore, the mass transfer coefficients can be expressed by a simple relationship, assuming that the equilibrium curve is a straight line.

$$\frac{1}{K_L} = \frac{1}{k_L} + \frac{C_o}{k_g\ H_A} \qquad (5)$$

Similarly

$$\frac{1}{K_G} = \frac{1}{k_g} + \frac{H_A}{k_L\ C_o} \qquad (6)$$

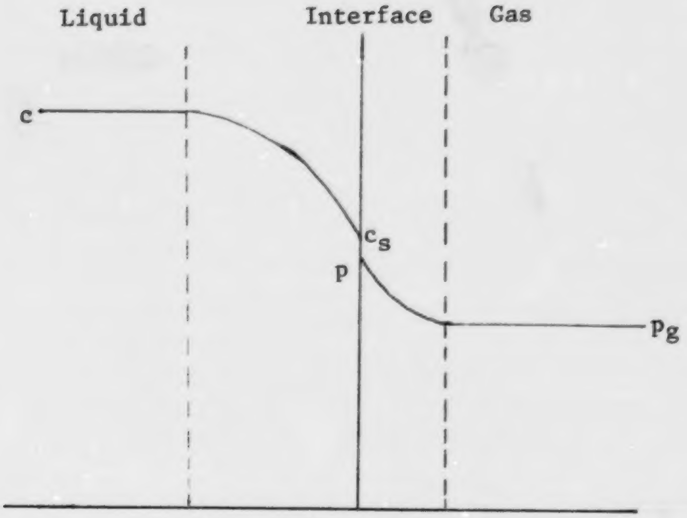

Liquid
Interface
Gas
c
c_s
p
p_g

Figure C.1: Schematic Representation of Interfacial Mass-transfer Process with Controlling Resistance Residing in Liquid Phase.

where

K_G = overall gas phase mass transfer coefficient

For volatiles in water these relationships can be further simplified (Kavanaugh, and Trussel 1980) as:

$$K_L \quad k_L \text{ and } K_G \quad \frac{k_L C_o}{H_A}$$

In most stripping operations the bulk of resistance to mass transfer resides in the liquid phase. Hence, for an effective mass transfer the liquid phase mass transfer coefficient should be maximized. This can be done by proper design of tower packings (in packed towers), thus also increasing the interfacial area.

The rate of mass transfer (N_A) can be expressed as (Treybal, 1968):

$$N_A = \frac{\text{(moles of A stripped)}}{\text{(time) (interfacial surface)}}$$

$$= \frac{d(LX_A)}{dZ} \qquad (7)$$

where

dZ = differential height of the tower (or depth of packing)

L = molar flow rate of the liquid

X_A = mole fraction of species in the liquid stream

From equation (3) it follows therefore that

$$\frac{d(LX_A)}{dZ} = K_L\, a\, (c^* - c) \qquad (8)$$

For dilute solutions the mole fraction X_A can be expressed as $X_A = c/c_o$ (Kavanaugh and Trussel, 1980), where c_o is the molar flux of water. Therefore, equation (8) can be integrated to a convenient form.

$$\int_o^z dZ = \frac{L}{K_L a C_o} \int_{X_{in}}^{X_{out}} \frac{dX_A}{X^*_A - X_A} \qquad (9)$$

The terms X_{in} and X_{out} are the molar concentrations of species in inlet and outlet liquid streams, and X_A is the equilibrium mole fraction of the species in the liquid stream. In mass transfer literature the right-hand side of equation (9) is conveniently represented by a product of two terms -- NTU, the number of transfer units, and HTU, the height of each transfer unit. Therefore,

$$Z = (HTU)\ (NTU) \qquad (10)$$

where

Z = height of the tower

$$HTU = \frac{L}{K_L a C_o}$$

$$NTU = \int_{X_{in}}^{X_{out}} \frac{dX_A}{X^*_A - X_A}$$

A transfer unit is a hypothetical quantity representing an equilibrium stage. Thus, NTU is the number of stages required to achieve the desired separation. It can be seen that to achieve 100% or complete separation would require infinite stages. Up to 99% separation efficiency can be achieved with a finite (reasonable) number of stages; this, of course, is dependent on the efficiency of mass transfer which is characterized by $K_L a$ and, indirectly, by HTU. Therefore, Z, is the height of continuous contacting tower required for the separation desired.

CHOICE OF AIR STRIPPING METHOD

Devices which could be used for air stripping include a:(1)

diffused aerator; (2) packed tower; (c) coke tray aerator, and (4) cross-flow tower (Kavanaugh and Trussel, 1980).

Diffused Aerator

Diffused aeration requires a basin into which water flows in from the top and exits from the bottom. Fresh air is bubbled into the basin at the bottom through a sparger or diffuser. As the air leaves the basin at the top it should carry the stripped volatile organics. The effectiveness of this mass-transfer is dependent on the size of bubbles and their residence time in the basin. Mechanical agitation improves the mass transfer process. Figure C.2 depicts a typical turbine aerator.

Packed Tower

In a packed tower, water and air flow counter-current to each other with maximum contact in the packing bed. Water flows down the bed after proper liquid distribution. Fresh air is forced up through the bed by forced or induced draft. Clean water is pumped away for ground water recharge or direct use. The void spaces in the packing allow maximum gas-liquid contact due to the increased interfacial area. There is no liquid holdup in the tower, unless flooding conditions exist; liquid holdup would result in a decreased efficiency. Figure C.3 shows a schematic representation of a packed tower.

Coke Tray Aerator

A coke tray aerator is essentially a plate tower with no forced flow of air. Water trickles down through the various trays which have

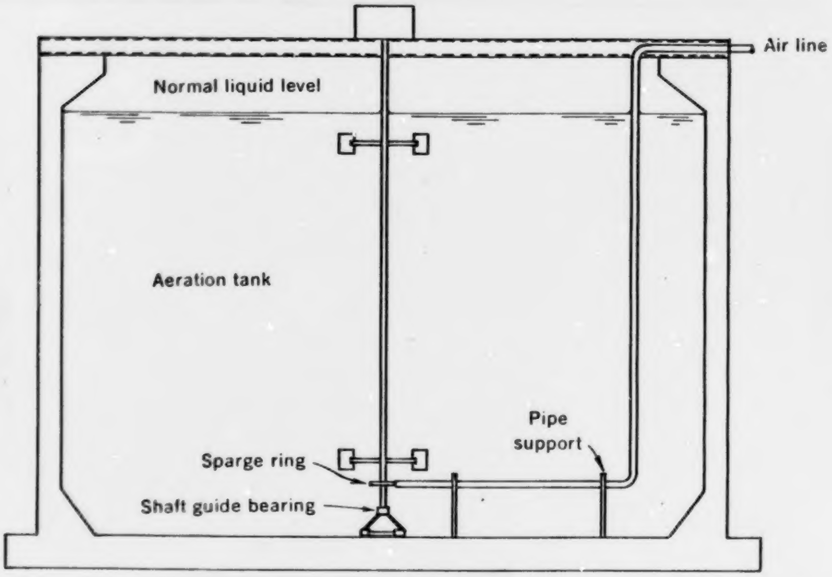

Air line
Normal liquid level
Aeration tank
Pipe support
Sparge ring
Shaft guide bearing

Figure C.2: Typical Turbine Aerator Installation.

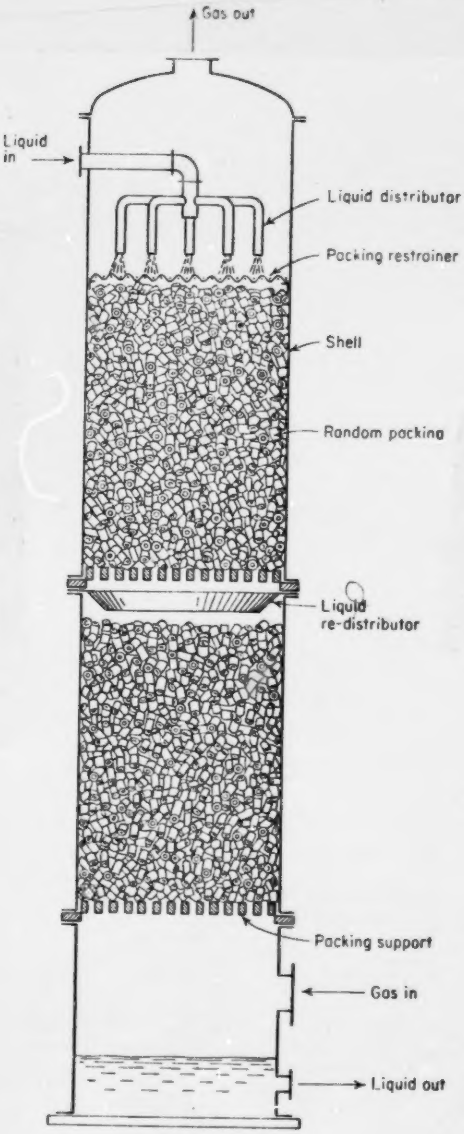

Gas out
Liquid in
Liquid distributor
Packing restrainer
Shell
Random packing
Liquid re-distributor
Packing support
Gas in
Liquid out

Figure C.3: Packed Tower.

coke on them, and gets stripped by the time it reaches the bottom. Coke acts as a medium in transferring the contaminants from water to the stationary air. The effectiveness of such a system can only be studied experimentally, since the air-to-water flow rate ratio cannot be controlled.

Cross-flow Tower

In a cross-flow tower water flows down from the top and air is drawn across the tower. For air stripping operations cross-flow towers have been designed and found to be less costly to build and operate (Thibodeaux, et al., 1977). Kavanaugh and Trussel (1980) suggest that cross-flow towers should also be considered for air stripping applications. The analytical methods for design are still under development.

Summary of Methods

Comparing diffused aeration and packed tower devices, it has been suggested (Kavanaugh and Trussel, 1980) that if the objective is to maximize removal of volatile contaminants from water, then packed tower aeration should be used. Studies need to be done to examine the suitability of coke tray aerators and cross-flow devices for effective air stripping of volatile organics from water.

DESIGN OF A PACKED TOWER

The computation of the number of transfer units for dilute solutions in a packed tower is greatly simplified, since the "operating line" is also a straight line (Treybal, 1968). A process schematic for a counter current packed tower is shown in Figure C.4. A material balance at the lower end of the column in Figure C.4 yields:

$$G\ (Y - Y_{in}) = L\ (X - X_{out}) \tag{11}$$

or $$Y = \frac{L}{G}\ (X - X_{out}) + Y_{in} \tag{12}$$

where

G = gas phase mass flow rate

Y_{in} = mole fraction of spcies in inlet gas to countercurrent packed tower

Y_{out} = mole fraction of species in outlet gas to countercurrent packed tower

L = liquid phase mass flow rate

X_{in} = mole fraction of species in inlet liquid to countercurrent packed tower

X_{out} = mole fraction of species in outlet liquid to countercurrent packed tower.

From Henry's law, the mole fractions of a species A in air and water are related as follows:

$$Y_A = \frac{H_A}{P_t}\ X_A{}^* \tag{13}$$

where

Y_A = mole fraction of contaminant A in gas phase

X^*A = mole fraction of contaminant A in liquid in equilibrium with gas phase

H_A = Henry's constant of contaminant A

P_t = total pressure

Therefore, a stripping factor R can be defined as (Kavanaugh and Trussel, 1980)

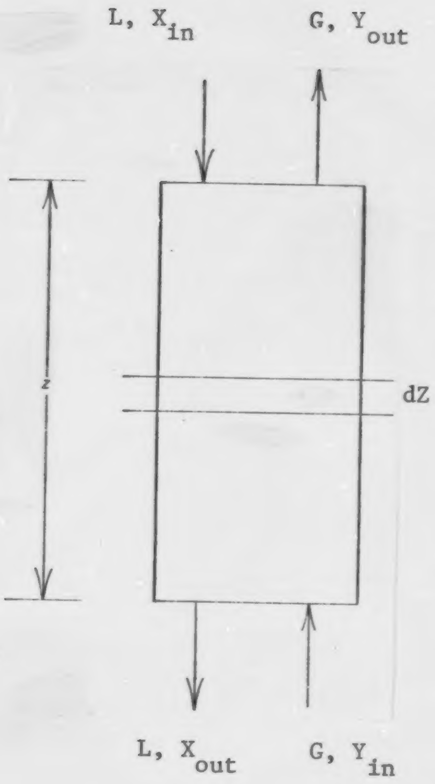

L, X_{in}
G, Y_{out}
z
dZ
L, X_{out}
G, Y_{in}

Figure C.4: Process Schematic for Countercurrent Packed Tower.

$$R = (\frac{H_A}{P_t})\ (\frac{G}{L}) \qquad (14)$$

Now integrating the expression for NTU with appropriate substitutions the following analytical solution is obtained.

$$NTU = (\frac{R}{R-1}) \quad \ln \frac{X_{in}/X_{out}\ (R-1) + 1}{R} \qquad (15)$$

Kavanaugh and Trussel (1980) have suggested a design procedure for countercurrent flow packed towers which contains the following steps:

(1) A proper packing material is selected which has a low packing factor and good mass transfer characteristics.

(2) For various stripping factors R in the range between 1 and 5, NTU's are computed for the required removal efficiency, at proper temperature and pressure.

(3) From design flooding and pressure correlation charts available in mass transfer literature allowable gas flow rates for each R value can be determined.

(4) The column diameter for the specified water flow rate is determined.

(5) Various correlations are available to determine the liquid phase mass transfer coefficient (K_La). Sherwood and Holloway's correlation (Perry and Chilton, 1973) can be used; the correlation is:

$$\frac{K_1 a_e}{D_1} = \propto (\frac{1}{\mu_1})^{1-n} \ {(\frac{\mu_1}{\rho_1 D_1}}^{0.5} \qquad (16)$$

where

K_1 = mass transfer coefficient (lb moles/hr sq ft)

a_e = effective area (sq ft/cu ft)

D_1 = diffusion coefficient for liquid (sq ft/hr)

L = liquid rate (lb/hr sq ft)

μ_l = liquid viscosity lb/hr ft)

ρ_l = liquid density (lb/cu ft)

H_l = height of a liquid phase transfer unit (ft)
= $L/(k_l\ a_e\ \rho_l)$

α,n = constants dependent on type and size of packing

(6) The Height of a transfer unit is determined for each value of L.

(7) Finally, the capital costs for packing height (Z), column diameter, volume of packing, and airflow rate for each value of R are determined.

The above procedure can be used to design a new countercurrent packed tower for air stripping. If a packed tower already exists, then the feasibility of using it for a particular stripping need can be evaluated using the same approach.

CASE STUDY RELATED TO GROUND WATER

Ground water is not free from contamination, with volatile organics being contaminants of current concern. Landfills, dumps, injection wells, septic tanks, sewage sludge, pesticides, and industrial waste disposal represent examples of various sources of contamination (Stover, 1982). Typically, over a long time period, contaminants can percolate through the bottom of a landfill or other surface source and into the ground water, thus causing pollution. Unlike in surface waters, volatile organics in ground water are not "naturally" aerated due to their minimal exposure to the atmosphere. Air stripping is one of the ways of treating ground water, and in terms of total organic carbon removal, Stover and Kincannon (1982) have concluded that steam stripping, when compared to air stripping, is a cost effective process for removal of volatile organics.

Examples of frequently encountered organic chemical contaminants in ground water include (Stover and Kincannon, 1982b): 1,1,1 trichloroethane; trichloroethylene; chloroform; benzene; toluene; vinyl chloride; xylene; methyl chloroform; and dibromo-chloropropane. Of these examples, the first two namely 1,1,1 trichloroethane (TCEA) and Trichloroethylene (TCE), typically occur in larger quantities in polluted ground water (Kelleher, Stover, and Sullivan, 1980; and Stover, 1982). Henry's constants for some of the above-listed compounds are in Table C.1 (Kavanaugh and Trussel, 1980). Higher values for Henry's constant indicates that the compound can be more easily stripped. Resistance to mass transfer for compounds with high Henry's constant values resides more in the liquid phase.

Kavanaugh and Trussel (1980) have reported that across the United States chlorohydrocarbon concentrations up to 1 mg/l have been frequently found in ground and surface water supplies. TCEA concentrations of 1200 μg/l have been found in well waters sampled by Kelleher, Stover and Sullivan (1980), whereas the Federal standard is 35 μg/l. Recent data collected near a hazardous waste dumpsite and reported by Stover and Kincannon (1982) show very high concentrations of TCEA (338 mg/l) and several other contaminants.

The design of an aeration device should be based on a contaminant which exists in high concentrations and is difficult to remove. TCEA seems to satisfy both conditions and is a convenient candidate to base an example design. Pilot air-stripping studies conducted by Kelleher,

Table C.1: Henry's Constants for Pollutants Which Might be Found in Ground Water

Compound	Formula	Henry's Constant (atm at 20°C)
1,1,1 trichloroethane	CCH_3Cl_3	400
Trichloroethylene	$CCHCl_3$	550
Chloroform	$CHCl_3$	170
Benzene	C_6H_6	240 (25°C)
Toluene	$C_6H_5CH_3$	340 (25°C)
Vinyl chloride	CH_2CHCl	355×10^3

Stover and Sullivan (1980) have indicated that removal of TCEA to less than 10 μg/l would remove several other volatile contaminants to less than 1.0 μg/l. One reason for this could be the very low concentrations of other organic contaminants compared to TCEA levels, in the conducted studies. Table C.2 illustrates the pollutant levels in the experimental ground water (Stover, 1982). Since TCEA is the major contaminant, the design is based on removal of TCEA, thus effectively reducing the concentrations of other contaminants. Starting with a water flow rate of 1900 gpm and assuming a design temperature of 20°C, the packed column can be designed to achieve 99.2% efficiency of removal of TCEA, that is, from 1,200 μg/l to 10 μg/l. The resultant design is as follows (Stover, 1982):

Air flow	1,910 cfm
Column diameter	8 feet
Packing height	38 feet
Packing material	1-inch Raschig rings

For the column designed to remove TCEA, an estimate can also be made for the expected effluent TCE concentrations for the same air-to-water ratio. The calculations indicate 99.4% removal of TCE, from 80 μg/l to 0.52 μg/l. The experimental data of Stover (1982) also imply a better removal percentage for TCE compared to TCEA, and it is reported that effluent concentrations of all other organic contaminants in the experimental ground water is less than 1.0 μg/l, when TCEA is reduced to 10 μg/l.

Table C.2: Pollutant Levels in Ground Water

Compound	Concentration (μg/l)
1,1,2 Trichloroethylene	80
1,1 Dichloroethylene	30
Trichlorofluoromethane	45
1,1,1-Trichloroethane	1,200
1,2-Trans-Dichlorethylene	40
1,1-Dichloroethane	35

COSTS OF AERATION

The cost of aeration equipment is dependent on the design considerations such as removal efficiencies, packing material chosen (if any) and other site-specific factors. From the literature, an estimate of costs can be obtained. Comparing carbon adsorption and aeration for removal of volatile organics, Kelleher, Stover, and Sullivan (1980) have concluded that aeration is a cheaper alternative. A recent EPA report (Federal Register, 1982) gives a summary of the preliminary costs for controlling TCE in drinking water. The alternatives of treatment considered are: (1) aeration -- packed tower, (2) aeration -- diffused; and (3) carbon adsorption. Aeration using a packed tower is the least expensive alternative, with diffused aeration being the most expensive. Love and Eilers (1982) have shown that a number of factors influence costs of organics removal from ground water.

DESORPTION RATE OF AIR STRIPPABLE ORGANICS IN GROUND WATER

Thus far in this appendix the concept of recycle has not been considered. A packed tower is typically designed to achieve a desired effluent volatile organics concentration in a "once-through" process. If the concentration of the contaminants in the influent stream are high, then in a given packed tower the effluent standards may not be attained. The effluent stream, or a part of it, could then be recycled, until the desired effluent concentration is attained. The time required for volatization of the organics depends on their volatization rate with respect to that of water. Thibodeaux (1974) and others have done extensive work with industrial waste water samples to determine volatization of air-strippable organics. This section reviews this work and its possible application to polluted ground water.

Figure C.5 shows a schematic representation of the recycling process. The specific volatization rate of a species i, K_i, can be defined as (Thibodeaux, et al., 1977):

$$K_i = (L_{mi} X_{ii} - L_{mo} X_{io})/L_{mi} X_{ii} \qquad (17)$$

where

L_{mi} = molar liquid flow rate into the packed section (moles/time·area)

L_{mo} = molar liquid flow rate out of the packed section (moles/time·area)

X_{ii} = concentration of species i entering the packed section (mole fraction)

X_{io} = concentration of species i leaving the packed section (mole fraction)

For a stripping factor, R, and height of column, Z, the following analytical model has been suggested for determining k_i:

$$K_i = 1 - \frac{(R-1)}{R \exp \left[(Z/HTU)_i \ (R-1)\right] - 1} \qquad (18)$$

An expression for the concentration-time history of a species is obtained by a differential balance on water and the volatile species, i, as follows:

$$X_{i(t)} = X_{io} \ [M_o/M_{(t)}] \ [(K_i/a') - 1] \qquad (19)$$

where

$X_i(t)$ = concentration of species at time t

X_{io} = initial concentration of species

$M_{(t)}$ = mass of water at time t

M_o = initial mass of water

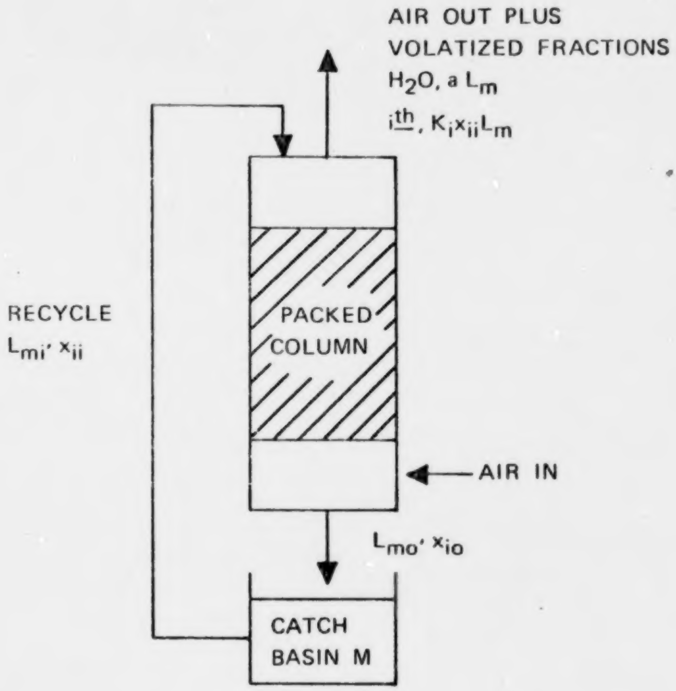

AIR OUT PLUS
VOLATIZED FRACTIONS
H_2O, a L_m
i^{th}, $K_i x_{ii} L_m$
RECYCLE
L_{mi}, x_{ii}
PACKED
COLUMN
AIR IN
L_{mo}, x_{io}
CATCH
BASIN M

Figure C.5: Schematic of Volatile Desorption Apparatus.

a' = specific volatization rate of water

Since not one but many organic species may be present in ground water, the use of a "pseudo-volatile component" has been suggested. Equation 19 can then be modified to

$$\log \ \Phi(t) = (K_s/a') \log [M_{(t)}/M_o] \qquad (20)$$

where

$\Phi(t)$ = $(F(t)-F_{nv}^o)/F_v^o$; F_{nv}^o being the fraction of non-volatiles and F_v^o the fraction of volatiles initially present; and F(t) being in $F_{(t)}$ = fraction of organics present at any time t.

K_s/a' = relative volatilization rate of the pseudo-volatile component

The total volatile organics present in a sample and their volatization rate can be determined if data on variations of concentrations and total mass of water with time is collected. A desorption apparatus which could be used for these determinations is shown in Figure C.6. For a ground water sample the data required would be measured as the TOC variation of the sample over a time period, and also the variation of the total mass of water. Thibodeaux, et al. (1977) have developed a computational algorithm that will output the values of F_v^o and K_s/a' for any set of data.

AIR POLLUTION CONSIDERATIONS

In decontaminating water by air stripping, the air gets the pollutant and thus the atmosphere surrounding the aeration device may become a concern due to air quality decreases. A concern has been expressed by Stover and Kincannon (1982) for the discharge of volatile organics into the atmosphere from stripping and other unit process.

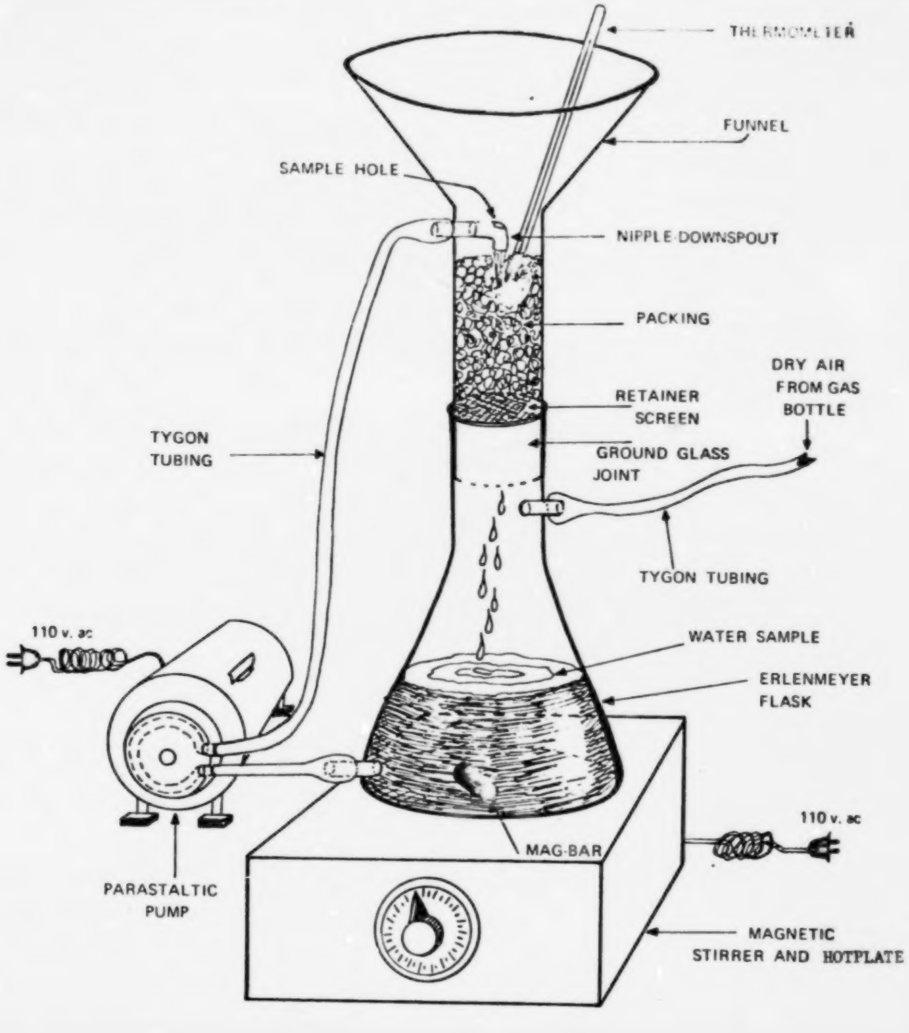

THERMOMETER
FUNNEL
SAMPLE HOLE
NIPPLE DOWNSPOUT
PACKING
RETAINER SCREEN
DRY AIR FROM GAS BOTTLE
TYGON TUBING
GROUND GLASS JOINT
TYGON TUBING
110 v. ac
WATER SAMPLE
ERLENMEYER FLASK
110 v. ac
MAG-BAR
PARASTALTIC PUMP
MAGNETIC STIRRER AND HOTPLATE

Figure C.6: Intalox Saddle Desorption Apparatus

Studies were conducted to clean up the "off-gas" from a steam stripping device. Activated carbon (carborundum GAC-40) was found very effective in adsorbing "all" the individual volatile organics present in the off-gas, at all loading rates (Stover and Kincannon, 1982).

An estimate of the air-strippable volatile organics and their relative desorption rates, indicates the potential magnitude of the air concerns. These estimates can be made by setting up a desorption apparatus, and testing samples of water, as suggested by Thibodeaux and Millican (1977). Atmospheric dispersal characteristics of the volatile organics in the off-gas could be studied and abatement strategies developed.

SELECTED REFERENCES

Eckenfelder, W.W., Industrial Water Pollution Control, 1966, McGraw-Hill Book Company, New York, New York.

Federal Register, Vol. 47, No. 43, Mar. 4, 1982, pp 9350-9358.

Kavanaugh, M.C. and Trussel, R.R., "Design of Aeration Towers to Strip Volatile Contaminants from Drinking Water", American Water Works Association Journal, Vol. 72, No. 12, 1980, pp 684-692.

Kelleher, D.L., Stover, E.L. and Sullivan, M., "Investigation of Volatile Organics Removal", Presented at New England Water Works Association Meeting, Randolph, Massachusetts, Jan. 17, 1980.

Love, O.T. and Eilers, R.G., "Treatment of Drinking Water Containing Trichloroethylene and Related Industrial Solvents", American Water Works Association Journal, Vol. 74, No. 8, 1982 pp 413-425.

Perry, R.H. and Chilton, C.H., editors, Chemical Engineer's Handbook, Fifth Edition, 1973, McGraw Hill, New York, New York.

Schroeder, E.D., Water and Wastewater Treatment, 1977, McGraw-Hill Book Company, New York, New York.

Stover, E.L., "Removal of Volatile Organics from Contaminated Ground Water", Proceedings of the Second National Symposium on Aquifer Restoration and Ground Water Monitoring, 1982, National Water Well Association, Oklahoma City, Oklahoma, Oct. 17-20, 1982.

Stover, E.L. and Kincannon, D.F., "Treatability Studies for Aquifer Restoration", Presented at the 1982 Joint Annual Conference Southwest and Texas Sections of American Water Works Association, Oklahoma City, Oklahoma, Oct. 17-20, 1982.

Thibodeaux, L.G., "Test Method for Volatile Component Stripping of Waste Water", EPA-660/2-74-044, May 1974, U.S. Environmental Protection Agency, Washington, D.C.

Thibodeaux, L.J. and Millican, J.D., "Quantity and Relative Desorption Rates of Air-Strippable Organics in Industrial Wastewaters", Environmental Science and Technology, Vol. 11, No. 9, Sept. 1977, pp 879-883.

Thibodeaux, L.J., et al., "Mass Transfer Units In Single and Multiple-Stage Packed Bed, Crossflow Devices", Industrial and Engineering Chemistry, Process Design Division, 1977, Vol. 16, No. 3, pp. 325 ff.

Treybal, R.E., Mass Transfer Operations, Second Edition, 1968, McGraw-Hill Book Company, New York, New York.

APPENDIX D

ACTIVATED CARBON ADSORPTION OF ORGANICS FROM GROUND WATER

INTRODUCTION

Many organic chemical compounds present in ground water can be removed by an activated carbon adsorption treatment process. Adsorption is a surface phenomena involving the attraction of the adsorbate onto the surface of the adsorbent. When the aqueous phase comes in contact with granular activated carbon, the organic compounds (adsorbate) become associated with the surface of the carbon particles (adsorbent). Adsorption has been used as an effective treatment technology after ground water withdrawal from aquifers (Kaufmann, 1982; Parmelle and Allan, 1982; Stover, 1982; and O'Brien and Fisher, 1983). Sources of ground water contamination by organics include leachate from lagoons and dumpsites; industrial accidents and spills; and spills resulting from railroad or truck accidents (O'Brien and Fisher, 1983). Examples of organic compounds found in ground water and the effectiveness of granular activated carbon treatment are shown in Table D.1 (O'Brien and Fisher, 1983).

ADSORPTION ISOTHERMS

In the adsorption of organic contaminants from ground water on the surface of carbon particles, the mass transfer will occur until equilibrium is reached. At equilibrium, there is a defined distribution of solute (organic pollutant) between the two solvent (water) and solid (activated carbon) phases. An adsorption isotherm describes this equilibrium relationship at a given temperature. Further, these isotherms are useful in predictive modeling and design of adsorption

Table D.1: Organic Compounds and their Removal

	Organic Compounds In Groundwater	Number Of Occurences	Influent (1) Concentration Range	Carbon Effluent (1) Concentration Achieved
1.	carbon tetrachloride	4	130 ug/1 - 10 mg/1	<1 ug/1
2.	chloroform	5	20 ug/1 - 3.4 mg/1	<1 ug/1
3.	dibromochloropropane	1	2 - 5 mg/1	<1 ug/1
4.	DDD	1	1 ug/1	<.05 ug/1
5.	DDE	1	1 ug/1	<0.05 ug/1
6.	DDT	1	4 ug/1	<0.05 ug/1
7.	CIS - 1,2 - dichloroethylene	8	5 ug/1 - 4 mg/1	<1 ug/1
8.	dichloropentadiene	1	450 ug/1	<10 ug/1
9.	diisopropyl ether	2	20 - 34 ug/1	<1 ug/1
10.	tertiary methyl-butylether	1	33 ug/1	<5.0 ug/1
11.	di isopropyl methyl phosphonate	1	1,250 ug/1	<50 ug/1
12.	1,3 - dichloropropene	1	10 ug/1	<1 ug/1
13.	dichloroethyl ether	1	1.1 mg/1	<1 ug/1
14.	dichloro isopropylether	1	0.8 mg/1	<1 ug/1
15.	benzene	2	0.4 - 11 mg/1	<1 ug/1
16.	acetone	1	10 - 100 ug/1	<10 ug/1
17.	ethyl acrylate	1	200 mg/1	<1 mg/1
18.	Trichlorotrifloroethane	1	6 mg/1	<10 ug/1
19.	methylene chloride	2	1 - 21 mg/1	<100 ug/1
20.	phenol	2	63 mg/1	<100 ug/1
21.	ortho chlorophenol	1	100 mg/1	<1 mg/1
22.	tetrachloroethylene	10	5 ug/1 - 70 mg/1	<1 ug/1
23.	trichloroethylene	15	5 ug/1 - 16 mg/1	<1 ug/1
24.	1, 1, 1 - trichloroethane	6	60 ug/1 - 25 mg/1	<1 ug/1
25.	vinylidiene chloride	2	5 ug/1 - 4 mg/1	<1 ug/1
26.	toluene	1	5 - 7 mg/1	<10 ug/1
27.	xylenes	3	0.2 - 10 mg/1	<10 ug/1

(1) Analyses conducted by Calgon Carbon Corporation conformed to Published U.S.E.P.A. protocol methods. Tests in the field were conducted using available analytical methods.

systems. The two most commonly used adsorption isotherms are the Langmuir and Freundlich isotherms.

The Langmuir equation has the following form (Suffet and McGuire, 1980):

$$q_e = \frac{Q^o\ b\ C_e}{1 + b\ C_e} \tag{1}$$

where

q_e = amount of adsorbate per unit weight of adsorbent in equilibrium with C_e

C_e = solution concentration

Q^o = amount of adsorbate per unit weight of adsorbent forming a complete monolayer on surface

$$b = b_o \exp(-E/RT) \tag{2}$$

where

b_o = constant containing the entropy term

E = energy of adsorption

R = universal gas constant

T = absolute temperature

The Freundlich equation has the following form (Dobbs and Cohen, 1980):

$$X/M = K\ C_f^{1/n} \tag{3}$$

where

X = amount of the compound adsorbed from a given volume of the solution = $C_o - C_f$

M = weight of activated carbon

C_o = amount of compound in the untreated solution

C_f = amount of compound remaining in treated water

K,n = characteristic constants of a compound

Some common organic compounds in ground water and their corresponding carbon adsorption capacities and the other Freundlich characteristics are listed in Table D.2 (Dobbs and Cohen, 1980). In determining the Freundlich isotherm characteristics, Filtrasorb 300 granular activated carbon was used as an adsorbent. Use can be made of the data in Table D.2 for calculating the carbon dosage required for desired removal efficiencies. For example, the Freundlich equation (Equation 3) for trichloroethene can be expressed as:

$$\frac{C_o - C_f}{M} = 28\ C_f^{0.62} \tag{4}$$

To serve as an example, assume that the trichloroethene concentration in ground water is 16 mg/l, and the desired concentration following activated carbon adsorption is 1 μg/l (0.001 mg/l). Therefore,

$$M = \frac{C_o - C_f}{28\ C_f^{\ 0.62}} = \frac{15.999}{28(0.001)^{0.62}}$$

$$= 41.4\ \text{g/l}$$

This is the carbon dosage required in a single stage process.

SINGLE AND MULTISTAGE ADSORPTION

In the adsorption of an organic compound from a dilute solution, the quantity of solvent (ground water in this case) can be assumed to remain constant. Preferential adsorption occurs, as a function of the concentration of the solute, temperature, solvent and type of adsorbent. For single components in water, the adsorption behavior can be represented by the adsorption isotherms, discussed in the previous section. In ground water many types of organic compounds may be present

Table D.2: Freundlich Isotherm Adsorption Characteristics for Several Organics

Organic	Adsorption Capacity, K(mg/g)	1/n	pH
Benzene	1.0	1.6	5.3
Carbon tetrachloride	11.0	0.83	5.3
Chloroform	2.6	0.73	5.3
Dichloroethylene	4.9	0.54	5.3
Methylene chloride	1.3	1.16	5.8
Phenol	21.0	0.54	--
Toluene	26.0	0.44	5.6
1,1,1-trichloroethane	2.5	0.34	5.3
Trichloroethene	28.0	0.62	5.3
Xylene	85.0	0.19	7.3

at varying concentrations. Competitive adsorption would occur, and the analysis of this phenomena is complicated. The theoretical analysis presented in this appendix is restricted to single-component adsorption, which would still be applicable to ground waters where interference from the rest of the components on one major component can be ignored. The concept of a "pseudo" compound based on the weighted concentrations of the individual components could be used to construct a representative Freundlich isotherm.

A single-stage batch treatment process can be used when a solute (component) in the liquid is strongly adsorbed relative to the rest of the solution. A schematic arrangement of equipment is shown in Figure D.1 along with a representation of the process (Treybal, 1968). From Figure D.1 and writing a mass balance relationship it follows that:

$$G_s\ (Y_0 - Y_1) = L_s\ (X_1 - X_0) \tag{5}$$

where

G_s = solvent entering and leaving single-stage adsorption system (lb.)

Y_0 = lb. solute per lb. solvent entering single-stage adsorption system

Y_1 = lb. solute per lb. solvent leaving single-stage adsorption system

L_s = adsorbent entering and leaving single-stage adsorption system (lb.)

X_1 = lb. solute per lb. adsorbent leaving single-stage adsorption system

X_0 = lb. solute per lb. adsorbent entering single-stage adsorption system

The equilibrium can be represented by an equation of the form:

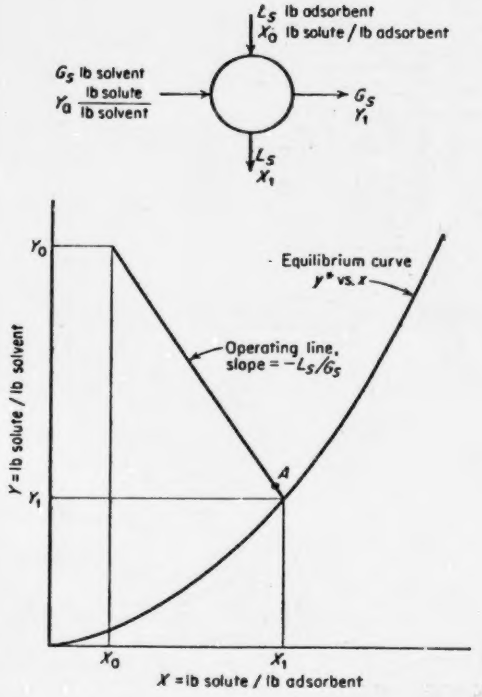

L_S lb adsorbent
X_0 lb solute / lb adsorbent
G_S lb solvent
Y_0 $\frac{\text{lb solute}}{\text{lb solvent}}$
G_S
Y_1
L_S
X_1
Y_0
Y_1
Y = lb solute / lb solvent
Equilibrium curve
y^* vs. x
Operating line,
slope = $-L_S/G_S$
A
X_0
X_1
X = lb solute / lb adsorbent

Figure D.1: Single-stage Adsorption

$$Y = mX^n \qquad (6)$$

This implies that at final equilibrium,

$$X_1 = (Y_1/m)^{1/n} \qquad (7)$$

Therefore, equation 5 modifies to a form similar to equation 3.

$$Y_0 - Y_1 = (L_s/G_s)(Y_1/m)^{1/n} \qquad (8)$$

A representation of the multistage (two-stage) crosscurrent operation is shown in Figure D.2 (Treybal, 1968). The mass balance equations are therefore:

$$G_s\ (Y_0 - Y_1) = L_{s1}\ (X_1 - X_0) \qquad (9)$$

$$G_s\ (Y_1 - Y_2) = L_{s2}\ (X_2 - X_0) \qquad (10)$$

By a similar analysis as above, the total adsorbent required can be shown to be:

$$\frac{L_{s1} + L_{s2}}{G_s} = m^{1/n}\left[\frac{Y_0 - Y_1}{Y_1{}^{1/n}} + \frac{Y_1 - Y_2}{Y_2{}^{1/n}}\right] \qquad (11)$$

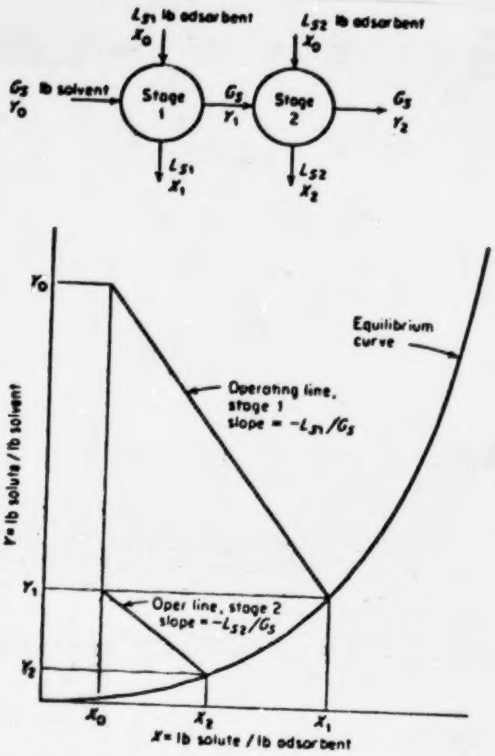
The intermediate concentration between the two stages can be found by minimizing the equation for total adsorbent (i.e., equation 11):

$$(Y_1/Y_2)^{1/n} - (1/n)(Y_0/Y_1) = 1 - 1/n \qquad (12)$$

Figure D.3 is a representation of a countercurrent flow system (Treybal, 1968). In the case of countercurrent flow the final equation takes the form:

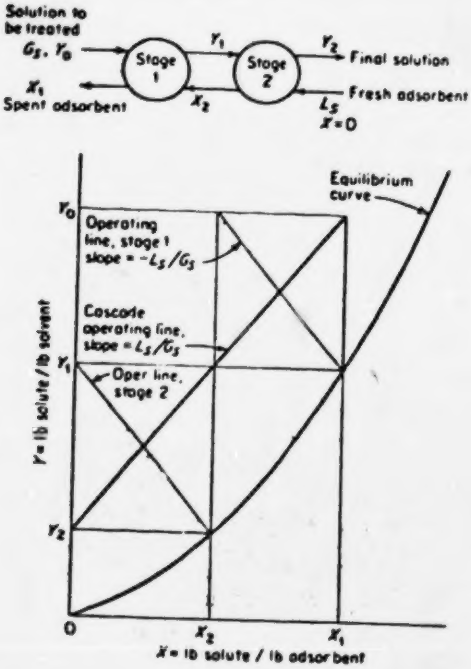
$$(Y_0/Y_2) - 1 = (Y_1/Y_2)^{1/n}\ (Y_1/Y_2 - 1) \qquad (13)$$

The carbon requirement as discussed earlier decreases with an increase in number of stages used, but approaches a minimum asymptotically. It is rarely economical to use more than two stages (Treybal, 1968).



L_{S1} lb adsorbent
X_0
L_{S2} lb adsorbent
X_0
G_S lb solvent
Y_0
Stage 1
G_S
Y_1
Stage 2
G_S
Y_2
L_{S1}
X_1
L_{S2}
X_2
Y_0
Equilibrium curve
Operating line, stage 1 slope = $-L_{S1}/G_S$
Y = lb solute / lb solvent
Y_1
Oper line, stage 2 slope = $-L_{S2}/G_S$
Y_2
X_0
X_2
X_1
X = lb solute / lb adsorbent

Figure D.2: Two-Stage Crosscurrent Adsorption



Solution to be treated
G_S, Y_0
Stage 1
Y_1
Stage 2
Y_2
Final solution
X_1
Spent adsorbent
X_2
Fresh adsorbent
L_S
$X = 0$
Equilibrium curve
Y_0
Operating line, stage 1 slope = $-L_S/G_S$
Cascade operating line, slope = L_S/G_S
Y_1
Oper line, stage 2
Y = lb solute / lb solvent
Y_2
0
X_2
X_1
X = lb solute / lb adsorbent

Figure D.3: Two-Stage Countercurrent Adsorption

FIXED BED ADSORPTION

The most commonly used adsorption system for contaminated ground water is the fixed bed system. It is more convenient and economical as compared to moving bed adsorption systems. For example, "a downflow fixed bed is more cost-effective than a pulsed bed for ground water treatment applications", and "a properly designed fixed bed can operate with the same carbon usage rate as a pulsed bed and costs less to build" (O'Brien and Fisher, 1983).

Fixed bed adsorption involves an unsteady state operation. The process is characterized by an adsorption wave as shown in Figure D.4 (Treybal, 1968). Maximum mass transfer occurs in a zone called the adsorption zone. This zone moves through the length of the column, after which the bed is considered saturated and ready for regeneration. In designing a system for a particular ground water pollution problem, it is desirable that the breakpoint and breakthrough curves for the particular situation be determined experimentally. An idealized breakthrough curve under isothermal conditions is illustrated in Figure D.5 (Treybal, 1968). The hatched area represented by U in Figure D.5 is the quantity of solute removed from the liquid in the adsorption zone from the breakpoint to exhaustion. The units of U would be lb solute/sq ft of bed cross-section. The term U can be determined by:

$$U = \int_{W_B}^{W_E} (Y_0 - Y)\, dw \qquad (14)$$

where

W_E = solute-free effluent at point of activated carbon bed exhaustion

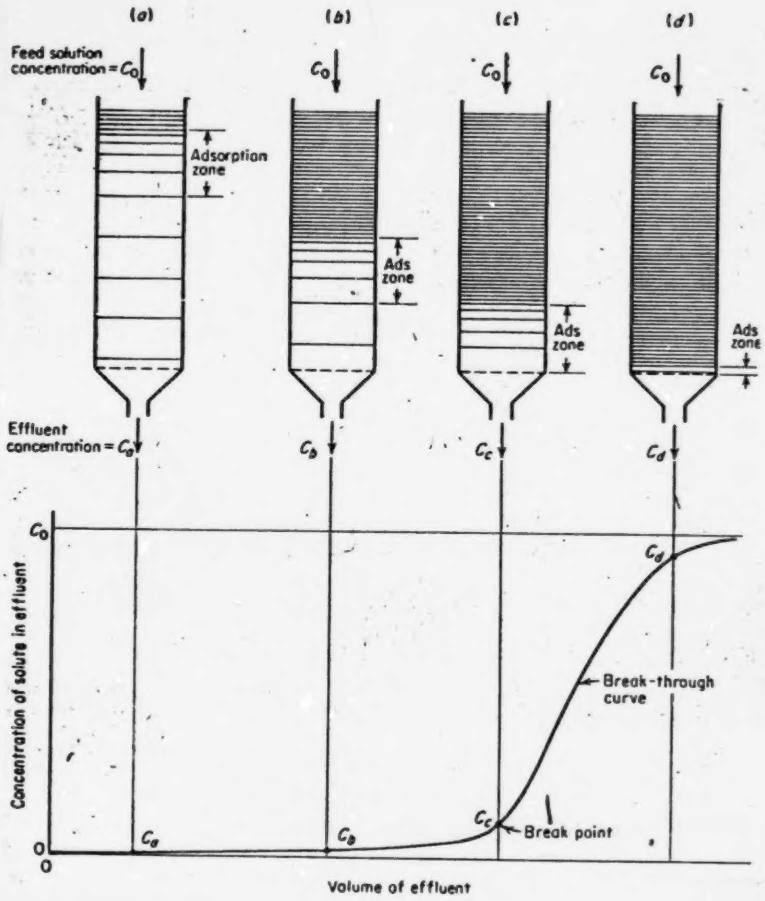

(a)
(b)
(c)
(d)
Feed solution concentration = C_0
C_0
C_0
C_0
Adsorption zone
Ads zone
Ads zone
Ads zone
Effluent concentration = C_a
C_b
C_c
C_d
C_0
C_d
Break-through curve
C_c
Break point
C_a
C_b
0
0
Concentration of solute in effluent
Volume of effluent

Figure D.4: The Adsorption Wave

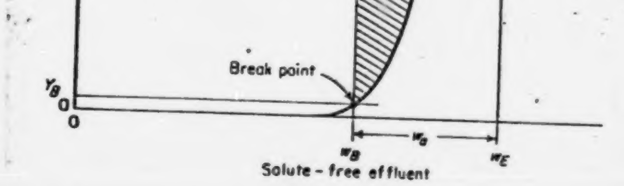


Figure D.5: Idealized Breakthough Curve

W_B = solute-free effluent at break point in activated carbon bed system

Y_0 = initial concentration of solute (pollutant) in solvent (ground water) (lb. solute/lb. solvent)

Y = concentration of solute (pollutant) in solvent (ground water) (lb. solute/lb. solvent)

dw = change in solute-free effluent

The fractional ability of the adsorbent still to adsorb solute at any time can be represented as (Treybal, 1968):

$$f = \frac{U}{Y_o W_a} = \frac{\int_{W_B}^{W_E} (Y_o - Y)\,dw}{Y_o W_a} \qquad (15)$$

where $W_a = W_E - W_B$

If Z is the activated carbon height of the column and Za the height of the adsorbing zone, then the degree of saturation of the column at breakpoint is,

$$\text{Degree of Saturation} = \frac{Z - f(Za)}{Z} \qquad (16)$$

For the purpose of this analysis, a moving bed can be assumed, and thus a stationary adsorption zone can be visualized, as shown in Figure D.6. The resulting equation would be of the form:

$$\frac{Z}{Z_a} \text{ at } Y = \frac{W - W_B}{W_a} = \frac{\int_{Y_B}^{Y} \frac{dy}{y - y^*}}{\int_{Y_B}^{Y_E} \frac{dy}{y - y^*}} \qquad (17)$$

A graphical solution of this equation will determine the breakthrough curve for any system.

Fixed bed adsorbers have been used widely for the treatment of ground water (O'Brien and Fisher, 1983). If more than one bed is used, they can be connected in series or parallel as shown in Figure D.7.

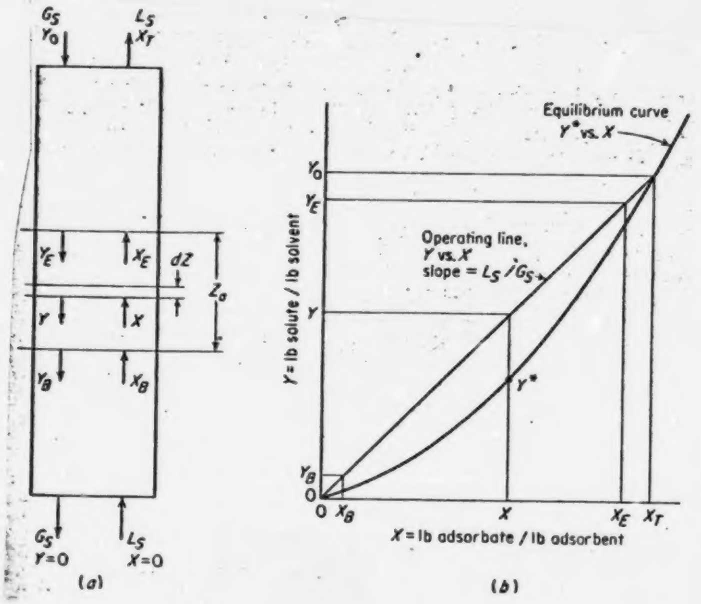
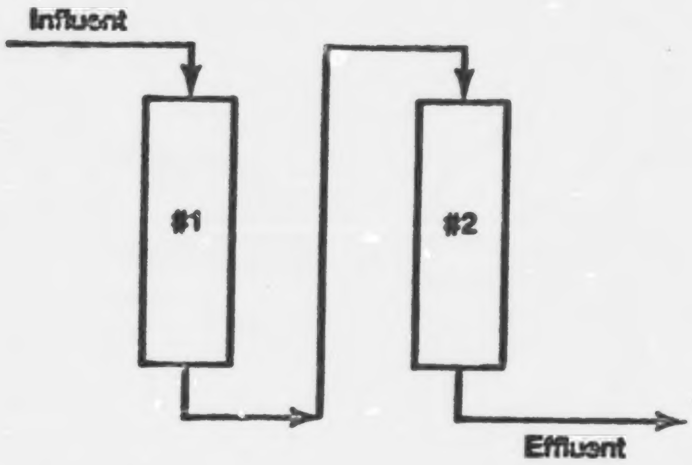

G_S
Y_O
L_S
X_T
Y_E
X_E
dZ
Z_a
Y
X
Y_B
X_B
G_S
Y=0
L_S
X=0
(a)
Equilibrium curve
Y* vs. X
Y_O
Y_E
Operating line,
Y vs. X
slope = L_S/G_S
Y
Y*
Y_B
0
0
X_B
X
X_E
X_T
Y = lb solute / lb solvent
X = lb adsorbate / lb adsorbent
(b)

Figure D.6: The Adsorption Zone

CARBON ADSORBERS IN SERIES OPERATION


Influent
#1
#2
Effluent

CARBON ADSORBERS IN PARALLEL, SINGLE FIXED BED OPERATION

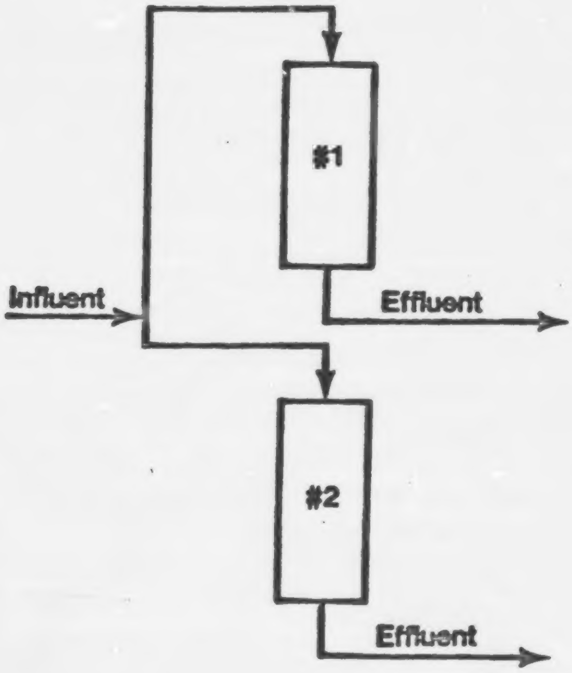

#1
Influent
Effluent
#2
Effluent

Figure D.7: Arrangements of Fixed Bed Adsorption Systems

Series operation is preferred if the organic compounds are present in increased numbers and higher concentrations. The resultant system contact time would be higher. For low concentrations and emergency treatment applications, the parallel operation could be used. Tables D.3 and D. 4 illustrate actual applications of the adsorption technology to polluted ground waters (O'Brien and Fisher, 1983).

PREDICTIVE MODEL FOR DESIGN

A computerized model called the Michigan Adsorption Design and Applications Model (MADAM) is useful in predicting fixed bed adsorption operations (Crittenden and Weber, 1978). This model can predict the concentration breakthrough profiles for various adsorbents, column configurations, hydrodynamic conditions, types of solutes and operational conditions. The MADAM model is based on the following theoretical development. In adsorption of solutes by porous adsorbents like granular activated carbon, the first step is the transport of the solute through a liquid film to the exterior of the adsorbent granules. Next is the diffusion of the solute through the pores of the adsorbent. Finally, adsorption of the solute on the interior surfaces of the adsorbent occurs. Surface diffusion is presumed to be the major intraparticle transport mechanism.

Based upon the theoretical assumptions and resultant mathematical equations, two key variables required for the use of the MADAM model are the surface diffusion coefficient and the external film mass transfer coefficient. Experimental studies are required to estimate the surface diffusion and external mass transfer coefficient for any system.

Table D.3: Operating Results -- Influent Contaminants at mg/l Levels

Source of Contaminants	Contaminants	Typical Influent Conc. (mg/l)	Typical Effluent Conc. (ug/l)
Truck spill	Methylene Chloride	21	< 1.0
	1,1,1-Trichloroethane	25	< 1.0
Rail Car Spill	Phenol	63	< 1.0
	Orthochloro-Phenol	100	< 1.0
Rail Car Spill	Phenol	32-40	< 10.0
	Vinylidine Chloride	2-4	< 10.0
Rail Car Spill	Ethyl Acrylate	200	< 1.0
Chemical Spill	Chloroform	3.4	< 1.0
	Carbon Tetrachloride	130-150	< 1.0
	Trichloroethylene	2-3	< 1.0
	Tetrachloroethylene	70	< 1.0
Chemical Spill	Chloroform	0.8	< 1.0
	Carbon Tetrachloride	10.0	< 1.0
	Trichloroethylene	0.4	< 1.0
	Tetrachloroethylene	10-20	< 1.0
On-Site Storage Tanks	ClS-1,2-Dichloroethylene	0.5	< 1.0
	Trichloroethylene	1.0	< 1.0
	Tetrachloroethylene	7.0	< 1.0
On-Site Storage Tanks	Methylene Chloride	1.5	< 100
	1,1,1-Trichloroethane	3.3	< 1.0
Chemical Spill	Dichloroethyl Ether	1.1	< 1.0
	Dichloroisopropyl Ether	0.8	< 1.0
Chemical Spill	Benzene	0.4	< 1.0
	Tetrachloroethylene	4.5	< 1.0
Landfill Site	TOC	20	< 5.0 mg/l
	Chloroform	1.4	< 1.0
	Carbon Tetrachloride	1.0	< 1.0
Gasoline Spill	Benzene	9-11	< 100

Table D.3: (continued)

Source of Contaminants	Contaminants	Typical Influent Conc. (mg/l)	Typical Effluent Conc. (ug/l)
On-Site Storage Tanks	Trichloroethylene	3-8	< 1.0
	Xylene	.2-.5	< 1.0
	Isopropyl Alcohol	.2	< 10.0
	Acetone	.1	< 10.0
On-Site Storage Tanks	1,1,1-Trichloroethane	12	< 5.0
	1,2 Dichloroethylene	0.5	< 1.0
	Xylene	8.0	< 1.0
Chemical Spill	DBCP	2.5	< 1.0
On-Site Well Storage Tanks	ClS-1,2-Dichloroethylene	0.2	< 1.0
	Trichloroethylene	0.5	< 1.0
	Tetrachloroethylene	2.0	< 1.0
Chemical By-Products	Di-Isopropyl Methyl Phosphonate	1.25	< 50
	Dichloropentadiene	0.45	< 10
Manufacturing Residues	DDT	0.004	< 0.5
	1,3 Dichloropropene	0.01	< 1.0
Chemical Spill	1,1,1-Trichloroethane	0.42	< 10
	Carbon Tetrachloride	0.464	< 10
	Trichlorotrifloroethane	5.977	< 10
	Tetrachloroethylene	5.800	< 10

Table D.4: Operating Results -- Influent Contaminants at ug/l Levels

Source of Contaminants	Contaminants	Typical Influent Conc. (ug/l)	Typical Effluent Conc. (ug/l)
Solvent Spill	1,1,1-Trichloroethane	143	< 1.0
	Trichloroethylene	8.4	< 1.0
	Tetrachloroethylene	26	< 1.0
Gasoline Tank Leakage	Methyl T-Butyl Ether	30-35	< 5.0
	Di-isopropyl Ether	30-40	< 1.0
	Trichloroethylene	50-60	< 1.0
On-Site Storage Tanks	Chloroform	300-500	< 100
	Trichloroethylene	5-10	< 1.0
Rail Car Spill	Chloroform	20	< 1.0
On-Site Storage Tanks	Trichloroethylene	30-250	< 1.0
Chemical Solvents	Trichloroethylene	30-40	< 1.0
	Tetrachloroethylene	140-200	< 1.0
Chemical Landfill	1,1,1-Trichloroethane	60-80	< 1.0
	1,1-Dichloroethylene	5-15	< 1.0
Gasoline Tank Leakage	Trichloroethylene	40-50	< 1.0
	Di-isopropyl Ether	20-30	< 1.0
Chemical Solvents	Trichloroethylene	20-25	< 1.0
	CIS-1,2-Dichloroethylene	10-15	< 1.0
On-Site Storage Tanks	Trichloroethylene	50	< 1.0
Chemical Spill	CIS-1,2-Dichloroethylene	5	< 1.0
	Trichloroethylene	5	< 1.0
	Tetrachloroethylene	10	< 1.0

Economic considerations

Organic compounds can be removed from ground water by three different techniques, namely: (1) diffused aeration, (2) carbon adsorption, and (3) packed tower aeration. The cost of treatment decreases in the same sequence (Federal Register, 1982). Packed tower aeration, though the cheapest, is effective only in the removal of "volatile" organics. Carbon adsorption is effective in the removal of most organic compounds, with a few exceptions such as low molecular weight compounds like amines, nitrosamines, glycols and certain ethers (Dobbs and Cohen, 1980). Cost information for activated carbon systems treating polluted ground water is available (Federal Register, 1980; Love and Eilers, 1982; and O'Brien and Fisher, 1983).

SELECTED REFERENCES

Crittenden, J.C. and Weber, W.J., "Predictive Model for Design of Fixed-Bed Adsorbers: Single-Component Model Verification", *Journal of Environmental Engineering Division, ASCE*, Vol. 104, No. EE3, June 1978, pp. 433-443.

Dobbs, R.A. and Cohen, J.M., "Carbon Adsorption Isotherms for Toxic Organics", EPA-600/8-80-023, Apr. 1980, U.S. Environmental Protection Agency, Municipal Environmental Research Laboratory, Cincinnati, Ohio,

Federal Register, Vol. 47, No. 43, March 4, 1982, pp. 9350-9358.

Kaufmann, H.G., "Granular Carbon Treatment of Groundwater Supplies", *Proceedings of the Second National Symposium on Aquifer Restoration and Groundwater Monitoring*, 1982, National Water Well Association, Worthington, Ohio, pp. 98-104.

Love, O. T. and Eilers, R.G., "Treatment of Drinking Water Containing Trichloroethylene and Related Industrial Solvents", *American Water Works Association Journal*, Vol. 74, No. 8, 1982, pp 413-425.

O'Brien, R.P. and Fisher, J.L., "Trace Organic Removal from Contaminated Groundwaters with Granular Activated Carbon", *Water Engineering and Management*, Vol. 130, No. 5, May 1983.

Parmele, C.S. and Allan, R.D., "Activated Carbon Adsorption with Nondestructive Regeneration -- An Economical Aquifer Restoration Technology", Proceedings of the Second National Symposium on Aquifer Restoration and Groundwater Monitoring, 1982, National Water Well Association, Worthington, Ohio, pp. 98-104.

Stover, E.L., "Removal of Volatile Organics from Contaminated Groundwater", Proceedings of the Second National Symposium on Aquifer Restoration and Groundwater Monitoring, 1982, National Water Well Association, Worthington, Ohio, pp. 77-84.

Suffet, I.H. and McGuire, M.J., Activated Carbon Adsorption of Organics from the Aqueous Phase, Volume 1, 1980, Ann Arbor Science Publishers, Inc., Ann Arbor, Michigan, pp. 15-36.

Treybal, R.E., Mass Transfer Operations, Second Edition, 1968, McGraw-Hill Book Company, New York, New York, 1968, pp. 491-556.

APPENDIX E

PUBLIC PARTICIPATION IN AQUIFER RESTORATION DECISION-MAKING

INTRODUCTION

The basic purpose of public participation is to promote productive use of inputs and perceptions from private citizens and public interest groups in order to improve the quality of environmental decision-making (Canter, 1977). This type of decision-making can be associated with the selection of aquifer restoration strategies in a given geographical area. These citizen-oriented activities are variously referred to as citizen participation, public participation, public involvement, and citizen involvement. Interest groups include those representative of industry, government, conservation, and preservation. This appendix has been prepared to highlight issues related to the planning and implementation of public participation programs.

The introduction section contains some basic definitions, and delineates general advantages and disadvantages of public participation. Additional issues to be addressed in this appendix include background information on public participation problems and constraints, delineating objectives for public participation, identification of publics, techniques of public participation, conflict management and resolution, and practical suggestions for implementation of a public participation program.

Basic Definitions

Public participation can be defined as a continuous, two-way communication process, which involves promoting full public understanding of the processes and mechanisms through which environmental problems and needs are investigated and solved by the responsible agency; keeping the public fully informed about the status and progress of studies and findings and implications of plan formulation and evaluation activities; and actively soliciting from all concerned citizens their opinions and perceptions of objectives and needs and their preferences regarding resource use and alternative development or management strategies and any other information and assistance relative to plan formulation and evaluation (Canter, 1977).

In essence, public participation involves both information feedforward and feedback. Feedforward is the process whereby information is communicated from public officials to citizens concerning public policy. Feedback is the communication of information from citizens to public officials regarding public policy. Feedback information should be useful to decision makers in making timing and content decisions (Canter, 1977).

Advantages and Disadvantages of Public Participation

There are advantages and disadvantages associated with public participation in environmental decision making. Benefits accrue when affected persons likely to be unrepresented in decision making processes are provided an opportunity to present their views (Canter, 1977). Creighton, Chalmers and Branch (1981) indicated that public participation can perform three vital functions: (1) serve as a mechanism for exchange of information; (2) provide a source of information on local values; and (3) aid in establishing the credibility of the planning and decision making process. Additional comments related to these three functions are (Creighton, Chalmers and Branch, 1981):

(1) Mechanism for Exchange of Information -- In order to provide the public with up-to-date information with which to assess study progress and options, it is necessary to summarize available planning and assessment information into short, succinct documents written in a language understandable to the public. Thus each public involvement activity becomes a natural point of synthesis for all the information generated during the study. The need to get information ready for public involvement provides a focus which can be otherwise missing, coming together only in a report at the end of the process. Public involvement is also a mechanism for obtaining information from the public. Much of this is in the form of values information, discussed below. But public involvement is also an indispensible component in the attempt to identify reliable information relevant to the planning and assessment problem at hand. The public (defined as everybody external to the agency conducting the study) is a major resource in identifying existing sources of information within the study area, thereby reducing search costs and the accidental duplication of previous work.

(2) Source of Information on Local Values -- Increasingly, environmental, economic-demographic and social assessment methodologies have been recognizing the need for a values context by distinguishing between "Impacts" and "Effects". "Impacts" are the events that will occur if an action is not taken, for example, contamination of the local ground water resource. "Effects" are an assessment of what that impact means in the impacted community, in light of community conditions and attitudes. Public involvement is a necessary methodology by which to get from the assessment that an impact will occur, to an understanding of the effect of that impact upon the community. Again, public involvement provides a framework that integrates the other forms of assessment.

(3) Establish Credibility of Planning and Decision Making Process -- The ultimate synergy of well-integrated assessment and decision making processes depends on their credibility in the eyes of potentially affected publics and in the eyes of the institution or group responsible for planning and implementing the proposed action. The credibility of any planning effort rests on the perception that the relevant issues were identified and addressed, appropriate information was obtained and correctly interpreted, and the significance of projected impacts assessed in the context of local values. Each of these criteria centers on the public involvement process. If the public perceives that it had access to the decision-

> making, if the role that public concerns and values had at each stage of the process is well documented, then the credibility of the process is enhanced. Effective public involvement often provides a kind of credibility within the planning agency as well. If the agency is confident that it is fully acquainted with public concerns and that a maximum effort has been made to incorporate public values into the planning process, it can commit to the implementation of the plan with a substantial increased confidence and security.

An additional benefit of public participation is that the agency, by constructing a record of decision making (one to several reports), provides for both judicial and public examination of the factors and considerations in the decision-making process. Thus an added accountability is placed on political and administrative decision makers since the process is open to public view. Openness exerts pressure on administrators to adhere to required procedures in decision making. Finally, through public participation the agency is forced to be responsive to issues beyond those of the immediate project (Canter, 1977).

Disadvantages, or costs, of public participation include the potential for confusion of the issues since many new perspectives may be introduced. It is possible to receive erroneous information that results from the lack of knowledge on the part of the participants. Additional disadvantages include uncertainty of the results of the process of public participation, as well as potential project delay and increased project costs. A properly planned public participation program need not represent a major funding item, and it need not cause an extensive period of delay in the process of decision making (Canter, 1977).

PUBLIC PARTICIPATION IN THE DECISION MAKING PROCESS

The decision making process can be considered to consist of six stages: (1) issues identification; (2) conduction of baseline study of the environment; (3) prediction and evaluation of impacts; (4) mitigation planning; (5) comparison of alternatives; and (6) decision-making relative to the proposed action. Public participation should be associated with all six stages (Canter, Miller and Fairchild, 1982).

The initial identification of issues is done to establish the scope of the decision making study. Public involvement at this stage is primarily devoted to informing the public about the project and getting to know what citizens feel about the problem being addressed. At this early stage, it will be possible to start identifying which groups see themselves as "winners" and which as "losers". The effort by the project planner should be to establish rapport and an air of cooperation.

The baseline study records the environmental status quo in the project area. At this stage, the flow of information to the public takes the form of what is being surveyed and why. Feedback to this information is often helpful in identifying existing data bases. Thus, the publics response can reduce the time and cost of the baseline survey.

Impact evaluation consists of the prediction and interpretation of changes due to project alternatives. The public can assist in this process in several ways. By reviewing the project alternatives being considered, they can ensure that no viable alternative is inadvertently omitted. Where legal standards are not in force, comments from the public can be useful in establishing project-specific criteria or maximum tolerable levels of change. Finally, the information-feedback cycle must be maintained to hold the public's interest and prevent alienation.

Mitigation measures are planned to reduce undesirable project effects. One of the major public inputs at this stage is ensuring that the mitigation measure is itself acceptable. Consider, for example, an aquifer restoration project that involves pumping of the polluted ground water and its treatment in an activated carbon plant located at the surface of the site. One mitigation measure might be to recharge the treated ground water. In many areas, particularly in the southwestern United States, this measure, though technically feasible, is culturally or legally unacceptable. As before, public review will ensure that all reasonable measures are considered.

The comparison of alternatives is done to determine the one or several preferred actions. Local values should be used to weight the importance of environmental factors at this stage. Some of the techniques which can be used to incorporate local social and cultural values into decision making methods will be discussed in a later section. It is very important at this stage that the public have an input into what is recommended to decision-makers.

It is at the comparison of alternatives stage that the preferred project alternative is identified. It is therefore at this stage that conflicts will come clearly into focus. Methods of conflict resolution will be discussed in a later section of this appendix. If the public involvement program has been effective to this point, it should be possible to resolve conflicts in a spirit of cooperation.

The final step in a decision-focused study for aquifer restoration is the actual decision on which alternative will be implemented. At this stage, public involvement has three objectives. The public should be informed what the decision is and why. Ideally, the decision should be based on the recommendations arising out of the comparison of alternatives. However, this is not always the case. The second objective is final resolution of conflicts. It may be necessary to compensate certain publics in order to even out the distribution of benefits. Finally, if the decision-makers are responsible to the public, there will be feedback concerning the final decision.

If public participation is to be effective in the various stages of the decision making process, the public participation program must be carefully planned. A good public participation program does not occur by accident (Canter, 1977). Planning for public participation should address the following elements:

(1) Delineation of objectives of public participation during the different stages.

(2) Identification of publics anticipated to be involved in the different stages.

(3) Selection of public participation techniques which are most appropriate for meeting the objectives and communicating with the publics. It may be necessary to delineate techniques for conflict management and resolution.

(4) Development of a practical plan for implementing the public participation program.

OBJECTIVES OF PUBLIC PARTICIPATION

The delineation of objectives of public participation during different stages within the decision making process is an important element in developing a public participation plan. The objectives could be general or specific. Hanchey (1981) suggested three general objectives which should be considered in the design of a public participation program for a specific planning situation, including an aquifer restoration program. These are referred to as: (1) the public relations objective; (2) the information objective; and (3) the conflict resolution objective. As shown in Figure E.1, these general objectives can be disaggregated into eight second-order objectives which serve to clarify and to provide workable concepts for both the design and evaluation of such programs (Hanchey, 1981). Additional comments on each of these objectives and subobjectives are as follows:

(1) Public Relations Objective -- The public relations objective is based on the premise that in order for the planning agency to develop plans which have broad public support and acceptance, the public must view the agency's role in the planning process as legitimate, and must have confidence and trust in the agency and its planning procedure. The need for legitimizing the agency's role in the planning process results from the fact that the public is frequently uninformed about the responsibilities and the authorities of the planning agency. Another important factor is the development of confidence and trust by the public toward the planning agency.

(2) Information Objective -- The information objective deals with the stage of the planning process in which the planner determines the problems to be solved during the planning effort and searches for solutions which are acceptable to the public. There are three separate concepts making up this objective: (1) the diagnosis of community problems and needs relative to aquifer restoration, (2) development of alternative solutions, and (3) the evaluation of the consequences of solutions. Quite frequently projects have been rejected by the public because the planner and the public

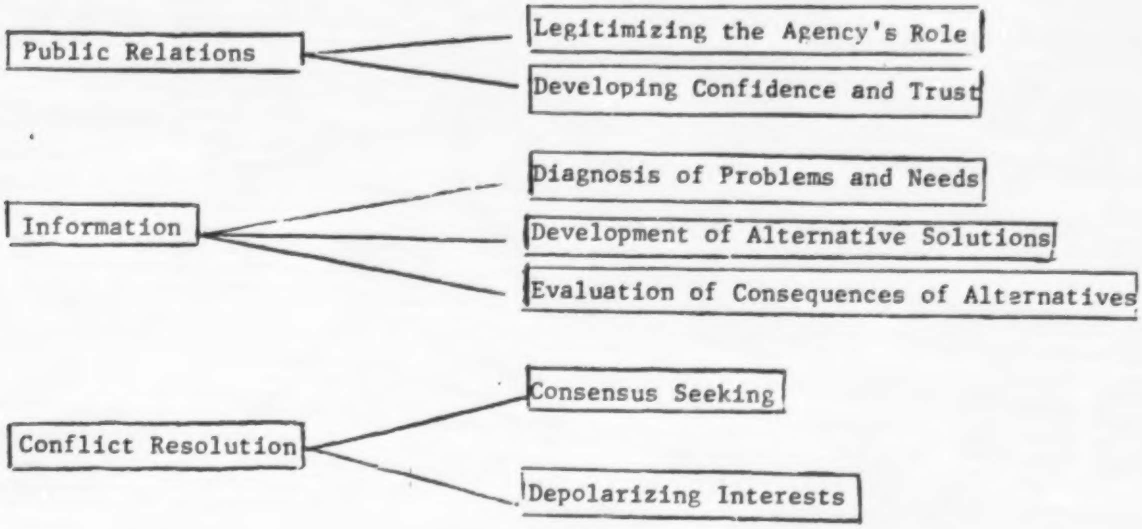

Public Relations
Legitimizing the Agency's Role
Developing Confidence and Trust
Information
Diagnosis of Problems and Needs
Development of Alternative Solutions
Evaluation of Consequences of Alternatives
Conflict Resolution
Consensus Seeking
Depolarizing Interests

Figure E.1: Objectives of Public Participation (Hanchey, 1981)

had a different view of the problems which needed solution. This is partly because people do not have the same values and thus do not perceive the same problems, even when viewing the same situation..

The need for involving the public during the development of alternative solutions stage of the study is based on the advantages to the planner of being able to test the social and political feasibility of alternatives early in the study. The purpose of public involvement at this early stage should be to allow the planner to begin to bracket the range of social and political feasibility early in the study, in order that more of the planning effort can be confined to plans more likely to be feasible and acceptable with the result that the planning process will more likely lead to a productive outcome. The planner should be careful, however, that he does not prematurely discard alternatives. This may happen for two reasons. First, it is very likely that the "public" as it is first encountered does not represent the full range of interests which will be affected by the ultimate plan and thus initial feasibility limits may not accurately reflect actual community feelings. Second, social and political feasibilities do not have fixed predetermined limits. They depend to a significant extent upon a clear understanding of the possibilities and the significance of choice. Thus, these limits are subject to change as the planning process progresses and increased information is exchanged between the participants.

(3) Conflict Resolution Objective -- Conflicts among the participants in a study may arise from differences in opinions or beliefs; it may reflect differences in interests, desires, or values; or it may occur as a result of a scarcity of some resource such as ground water. Conflict can occur in a cooperative or competitive context and will be strongly influenced by the processes of conflict resolution employed by the planner. There are two concepts which are useful in describing a favorable approach to conflict resolution, consensus seeking and the avoidance of extreme positions. It should be noted that these components of the conflict resolution objectives are not independent of the other two objectives; rather they are influenced to a great extent by the degree to which the planner has been successful in achieving the other objectives. Consensus seeking can be described as cooperative problem solving in which the conflicting parties have the joint interest of reaching a mutually satisfactory solution. Quite frequently, conflicts over issues have been perceived by participants as situations where a party to the conflict can take only one of two positions: for or against. This is unfortunate in that it implies that what is good for one party is necessarily bad for

> the other. Anyone who perceives it as such, must of course, align himself with one of the two positions.

Bishop (1975) delineated six objectives for public participation and tied them to the various stages of the decision making process. The six general objectives are:

(1) Information, education, and liaison.

(2) Identification of problems, needs, and important values.

(3) Idea generation and problem solving.

(4) Reaction and feedback on proposals.

(5) Evaluation of alternatives.

(6) Conflict resolution consensus.

The relationship of these objectives to the six stages in the decision making process are shown in Table E.1 (Bishop, 1975). The first of these objectives is directed toward education of the citizenry on the decision making process, its purpose, and the process of citizen participation. In addition, this objective includes dissemination of information on the study progress and findings, as well as data on potential environmental issues.

Identification of problems, needs, and important values is related to the determination of the environmental resources, including surface and ground water resources, important to various segments of the public in an area. In addition, this objective is focused on defining areas of ground water pollution and the relation of potential solutions being addressed in the project study.

The third objective is directed toward identification of alternatives that may not have been considered in normal planning

Table E.1: Public Involvement Objectives at Various Decision Making Process Stages (Bishop, 1975)

	Assessment Stage					
Objective	Issues Identification	**Baseline Study**	Impact Evaluation	Mitigation Planning	Comparison of Alternatives	Decision-Making
Inform/Educate	X	X	X	X	X	X
Identify Problems/ Needs/Values	X	X	X	X	X	
Approaches to Problem Solving			X	X		
Feedback		X	X	X	X	X
Evaluate Alternatives			X	X	X	
Resolve Conflicts					X	X

processes for aquifer restoration. In addition to specific alternatives for identified needs, it is possible also to enumerate mitigating measures for various alternatives so as to minimize adverse environmental effects. The fourth objective attempts to probe public perceptions of the actions and resource interrelations. In addition, this objective can be used to assess significance of various types of impacts. The alternatives evaluation objective is closely related to reaction and feedback on proposals for aquifer restoration. In the process of evaluation of alternatives, valuable information can be received about the significance of unquantified and quantified environmental amenities. Public reaction to value trade offs in the process of selection can also be assessed.

The final objective is related to resolving conflicts that exist over the proposed program for aquifer restoration. This objective may involve mediation of differences among various interest groups, development of mechanisms for environmental costs compensation, and effort directed toward arriving at a consensus opinion on a preferred program. Succesful accomplishment of this objective can avoid unnecessary and costly litigation.

Extensive communication will be necessary to achieve the objectives of public participation. Bishop (1981) identified the following four communications process models which seem appropriate in meeting the basic objectives of public participation: (1) diffusion process; (2) collection process; (3) interaction process; and (4) diffusion-collection process. Explanations for these four models are as follows (Bishop, 1981):

(1) Diffusion Process -- There is the possibility of multiple access to target groups or publics through the communications system. An operational example of this is illustrated in Figure E.2. In this process, the agency sends a message via different media to various target groups, who in turn transmit the message to still other groups or individuals. The net result enables the agency to reach a broader segment of the public in terms of the total impact than just the initial target group. The diagram in Figure E.2 brings out three important points. First, communication is not just a single, but a multi-step process where target groups become senders in transferring a message to others through media which they can access. Corrollary to this is the fact that the sender cannot completely control the communication process since intermediaries are present to influence or interrupt the process. Second, a target public can be contacted through several media, thus giving opportunity for reinforcing and clarifying the message. Third, if some media are inoperative due to frame of reference or noise problems, the diffusion process can still get the message to target groups through other media types.

(2) Collection Process -- The collection process can be seen as diffusion in reverse. It may serve to obtain feedback to complete a communication look or to collect information. The messages may or may not return by the same media.

(3) Interaction Process -- Interaction describes the situation where communication is an interchange among several groups, as illustrated in Figure E.3. The agency may assume the central role in acting as a moderator and facilitator in the communication exchange among other groups, or may simply take the role of one of the communicators in the interaction. The interactive processes generally imply communications media which involve meetings, work groups, committees, advisory panels, and the like.

(4) Diffusion-Collection Processes -- This process describes the situation where information is disseminated with the specific intent of eliciting some desired information in response. Usually, in addition, the mechanism or medium for response will be specified or provided in order to facilitate information collection. A simple example is a questionnaire that is sent to some public groups and to a newspaper (see Figure E.2). Target publics are asked to send their responses by individual letter to the agency as the originator of the questionnaire.

The communications process models can be matched with the key objectives of public participation. These cross-comparisons as shown in

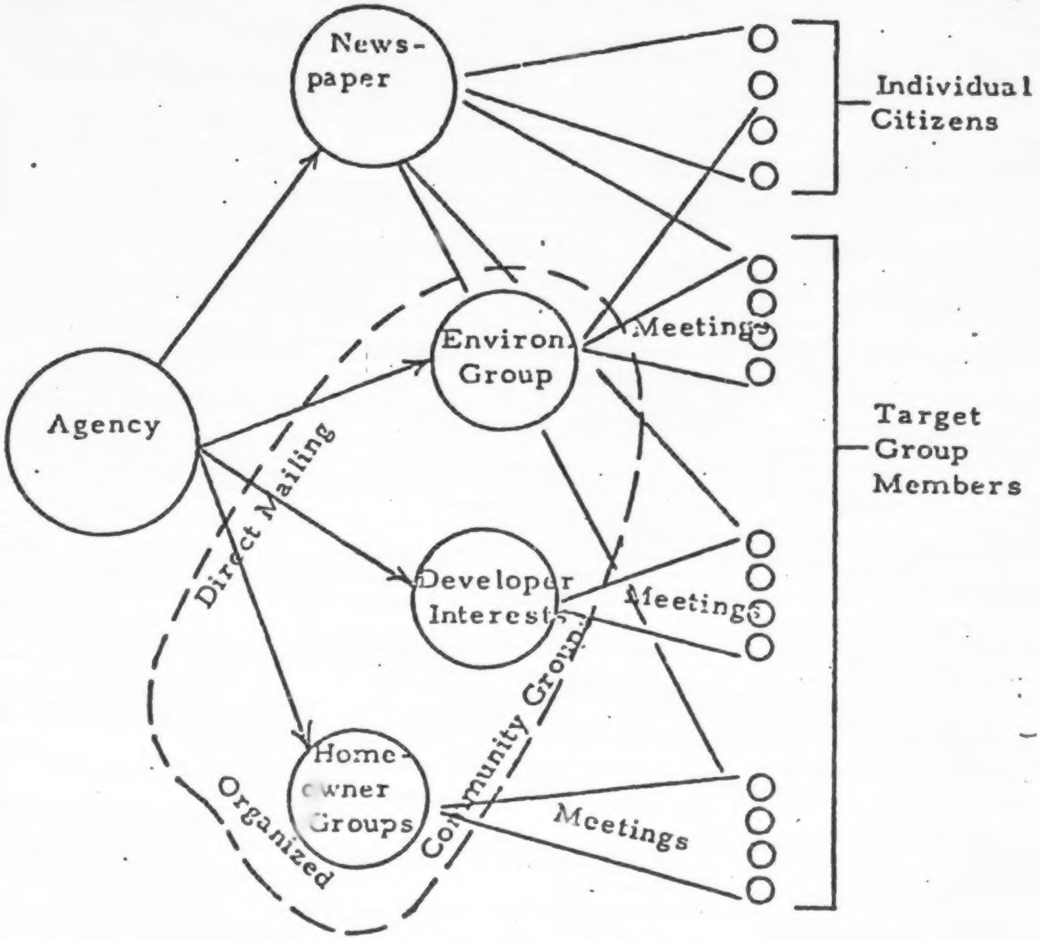

News-paper
Individual Citizens
Environ. Group
Meetings
Agency
Target Group Members
Direct Mailing
Developer Interests
Meetings
Community Group
Home-owner Groups
Meetings
Organized

Figure E.2: Example of a Diffusion Process (Bishop, 1985)

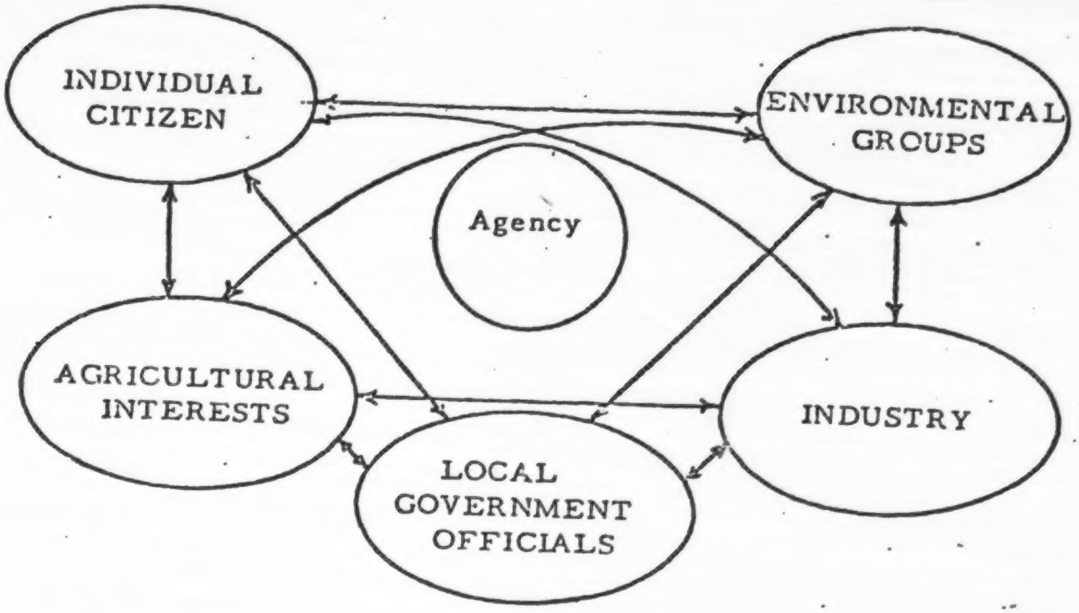

INDIVIDUAL CITIZEN
ENVIRONMENTAL GROUPS
Agency
AGRICULTURAL INTERESTS
INDUSTRY
LOCAL GOVERNMENT OFFICIALS

Figure E.3: An Interaction Process (Bishop, 1981)

Figure E.4 (Bishop, 1981) can aid in selecting an approprite communications approach for meeting a particular objective. For example, the inform, educate, and liaison objectives are all dependent on dissemination of information. The diffusion model describes this process. Identification, assessment, and feedback are objectives that are described by the reverse, the collection model. Idea generation, problem-solving, conflict resolution, and consensus are generally best accomplished by interaction processes. Review, reaction, and evaluation objectives require a two-step process. An information "stimulus" is first directed to the "publics", then the publics respond with their reactions or evaluations. A total communication process will usually require all of these processes (Bishop, 1981).

IDENTIFICATION OF PUBLICS

The identification of publics which would potentially be involved in the various stages of the decision making process is another basic element in the development of a public participation program. Also of importance is the delineation of public participation techniques which are most effective in communicating with different publics. This section of this appendix will address the recognition of types of publics, pragmatic approaches for identifying publics, and selected techniques for communicating with identified publics.

Recognition of Types of Publics

The general public cannot be considered as one body. The public is diffuse, but at the same time highly segmented into interest groups, geographic communities, and individuals. There are sets or groups of

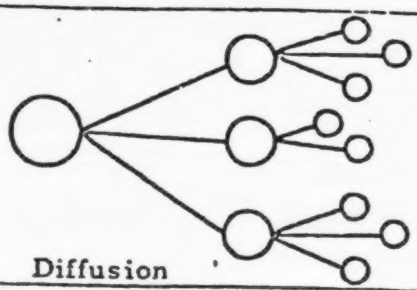
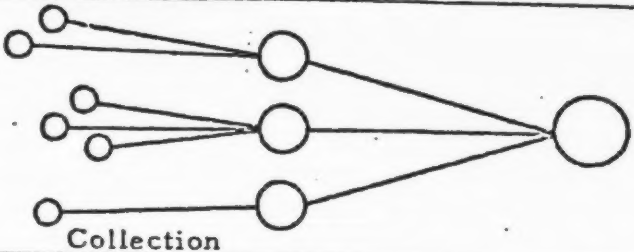
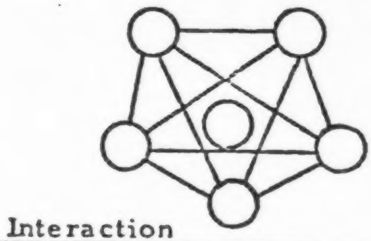
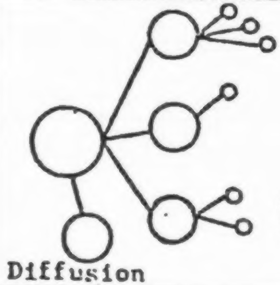
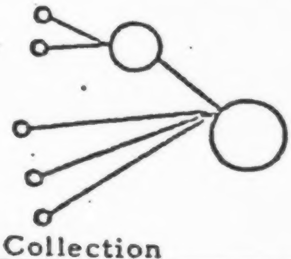
Objective, Action, Words	Models
Inform, educate, review, liaison	
Identification, assessment, feedback, liaison	 Collection
Idea generation, problem solving, resolving conflicts, consensus	 Interaction
Reaction, evaluation, review and comment	  Collection

Figure E.4: Correspondence of Communications Objectives and Models (Bishop, 1981)

"publics" that have common goals, ideals, and values. Any one person may belong to several different sets of these publics since they may be professionally, socially, or politically oriented. The Venn diagram shown in Figure E.5 illustrates the overlapping of some of these groups, and the fact that an individual may identify with one, a combination of two, or all three of the groups (Bishop, 1981). Two significant points may be drawn from Figure E.5 in terms of communication:

(1) Individuals are likely associated with various social, economic, and cultural orientations from which they draw their information and structure their values.

(2) Multiple association thus allows the opportunity for multiple access to individuals as participants, clients, or critics in a planning process.

Schwertz (1979) suggested that the purpose of identifying the various publics is two-fold. The first is to ensure that no group of persons is excluded from participating. Such exclusion, whether intentional or not, will be resented. Those who are left out will often seek redress outside of the formal public involvement program; for example, by court action. The second purpose relates to the public involvement technique to be used. Some techniques are more effective with certain groups than others.

There are several ways of categorizing various publics that might be involved in a public participation program for an aquifer restoration project. One group of publics consists of four separate categories (Canter, 1977):

(1) Persons who are immediately affected by the project and live in the vicinity of the project.

(2) Ecologists ranging from preservationists to those who want to ensure that development is as effectively integrated into the

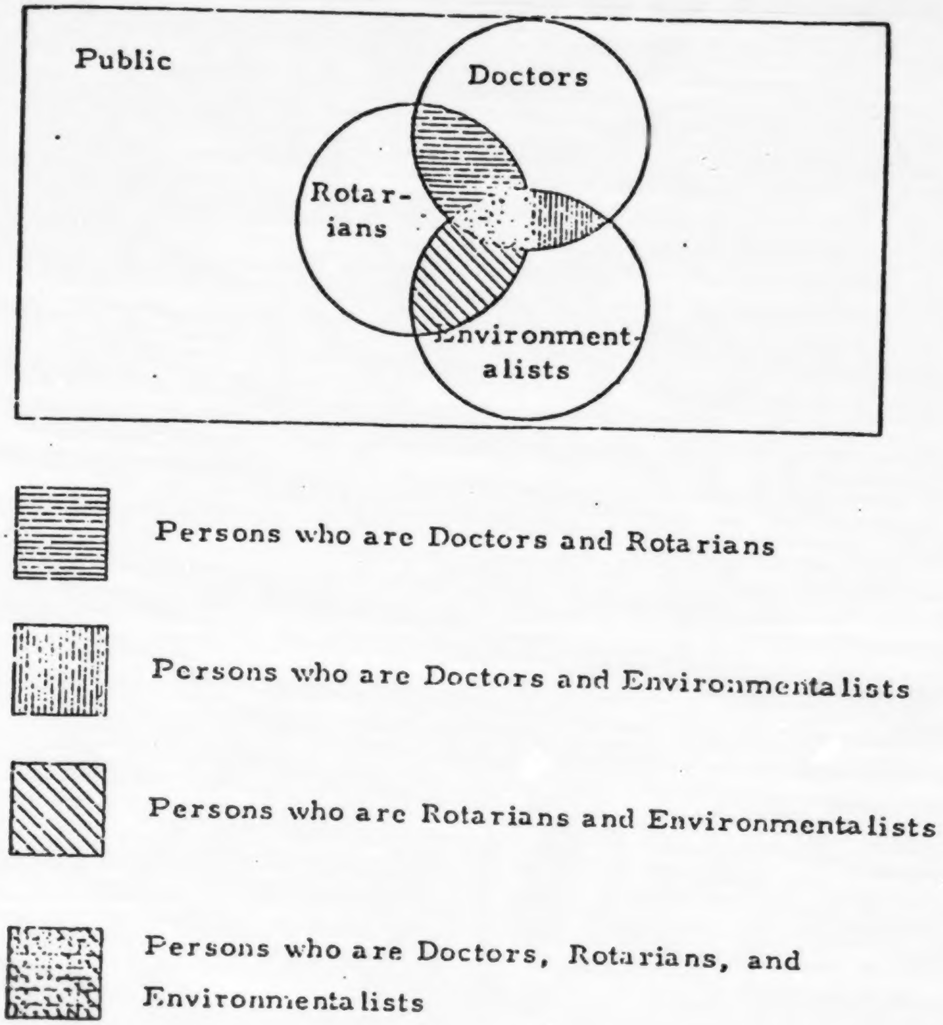

Public
Doctors
Rotar-
ians
Environment-
alists
Persons who are Doctors and Rotarians
Persons who are Doctors and Environmentalists
Persons who are Rotarians and Environmentalists
Persons who are Doctors, Rotarians, and Environmentalists

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Figure E.5: Example of Multiple Public Associations (Bishop, 1981)

needs of the environment as possible. Persons in this group are willing to incur substantial financial costs for environmental protection.

(3) Business and commercial developers who would benefit from initiation of the proposed action.

(4) The part of the general public who enjoy a high standard of living and who do not want to sacrifice this standard.

The U.S. Army Corps of Engineers has defined the following publics in conjunction with water resources development projects (U.S. Army Corps of Engineers, 1971). While oriented to surface water projects, many, if not all, of the following publics might be associated with aquifer restoration projects:

(1) Individual citizens, including the general public and key individuals who do not express their preferences through, or participate in, any groups or organizations.

(2) Sporting groups.

(3) Conservation/environmental groups.

(4) Farm organizations.

(5) Property owners and users, representing those persons who will be or might be displaced or affected by any alternative under study.

(6) Business and industrial groups, including Chambers of Commerce and selected trade and industrial associations.

(7) Professional groups and organizations, such as the American Institute of Planners, American Society of Civil Engineers, and others.

(8) Educational institutions, including universities, high schools, and vocational schools. General participation is by a few key faculty members and students or student groups and organizations.

(9) Service clubs and civic organizations, including service clubs in a community such as Rotary Club, Lions Club, League of Women Voters, and others.

(10) Labor unions.

(11) State and local governmental agencies, including planning commissions, councils of government, and individual agencies.

(12) State and local elected officials.

(13) Federal agencies.

(14) Other groups and organizations, possibly including various urban groups, economic opportunity groups, political clubs and associations, minority groups, religious groups and organizations, and many others.

(15) Media, including the staff of newspapers, radio, television, and various trade media.

In targeting publics an attempt is made to identify those persons who believe themselves to be affected by the aquifer restoration project outcome. The difficulty is that the degree to which people feel affected by a project is a result of their subjective perception; people the agency feels are most directly impacted may not be as concerned as someone that the agency perceives as only peripherally involved. However, the starting point always remains some effort to objectively analyze the likelihood that someone will feel affected by the study. Some of the bases on which people are most likely to feel affected are (Creighton, 1981c):

(1) Proximity: People who live in the immediate area of a project and who are likely to be affected by noise, dust, or possibly even threat of dislocation, are the most obvious publics to be included in the study.

(2) Economic: Groups that have jobs to gain or competitive advantages to win, e.g., industrial developers requiring water, are again an obvious starting point in any analysis of possible publics.

(3) Use: Those people whose use of the area is likely to be affected in any way by the outcome of the project are also likely to be interested in participating.

(4) Social: Increasingly, people who see projects as a threat to the tradition and culture of the local community are likely to

be interested in projects. They may perceive that a large influx of construction workers into an area may produce either a positive or negative effect on the community. Or they may perceive that the project will allow for a substantial population growth in the area which they may again view either positively or negatively.

(5) Values: Some groups may be only peripherally affected by the first four criteria but find that some of the issues raised in the study directly affect their values, their "sense of the way things ought to be". Any time a study touches on such issues as free enterprise vs. government control, or jobs vs. environmental enhancement, there may be a number of individuals who participate primarily because of the values issues involved.

Pragmatic Approaches for Identifying Publics

Recognizing that there are different types of publics based on different classification schemes, the issue then turns to pragmatic approaches for identifying the potential publics which might be associated with the decision making process during its various stages. Creighton (1981c) suggested three broad approaches to targeting the public: (1) self-identification; (2) third party identification; and (3) staff identification.

Self-identification simply means that individuals or groups step forward and indicate an interest in participating in the decision making process. The use of the news media, the preparation of brochures and newsletters, and holding of well-publicized public meetings are all means of encouraging self-identification. Anyone who participates by attending a meeting or writing a letter or phoning on a hot line has clearly indicated an interest in being an active public in the decision making process. As a result it is critical that anyone who expresses an interest in the process in any way quickly is placed on the mailing list and is continually informed of progress in the process (Creighton, 1981c).

One of the best ways to obtain information about other interests or individuals which should be included in the study is to ask an existing advisory committee, or representatives of known interests, who else should be involved. One variation on this theme is to enclose a response form in any mailings inviting people to suggest other groups that should be included. These simple techniques of consulting with known representatives to recommend others who should be involved often prove to be one of the most effective means of targeting the public (Creighton, 1981c).

There is a wide range of techniques by which internal staff can systematically approach targeting the public. These include (Creighton, 1981c):

(1) Intuitive/experimental information: Most planning staff that have worked in an area for some period of time can, if asked, immediately begin to identify individuals and groups that are likely to be involved in any new study. One of the richest sources of information for possible individuals or interests to be involved would be internal staff who have worked in the area for some period of time.

(2) Geographic analysis: In many cases just by looking at a map it is possible to identify publics who reside in a project site area and adjacent to it.

(3) Historical analysis: In many cases there is considerable information in old files. This includes:

  (a) Lists of previous participants in earlier studies included in reports.

  (b) Correspondence files.

  (c) Newspaper clippings regarding similar studies.

  (d) Library files on past projects.

(4) Consultation with other agencies: Since numerous agencies have held public involvement programs it can often be useful to explore their files or consult with them concerning possible publics.

Schwertz (1979) noted that many communities have existing organizations or interest groups which can and should be made a part of a public participation program. Many of these organizations have been created to address specific community problems. Other organizations, such as the local Chamber of Commerce, the Jaycees, or the League of Women Voters, are also active in many phases of community life. Table E.2 contains a citizen involvement checklist which can be useful for the public participation program planning staff in identifying publics which would be potentially associated with a project.

While the mailing lists may be a useful tool for notifying parties of public meetings, there are problems in using them as the primary basis for identifying people for more intensive public participation (Ragan, Jr., 1981a). First, because public meetings are "official" sessions, fully 75 to 80 percent of most mailing lists comprise public officials and agencies (as many as 45 percent are Federal, with many of these in national or regional offices). Private organizations and individuals are not more strongly represented on the lists simply because they are much harder to identify. Second, mailing lists are hard to maintain; a study manager may not have the time. Third, many mailing lists may overlap and duplicate names of individuals or organizations. Fourth, mailing lists categorized by public organization, media, and all others make it difficult to identify potential interests to be contacted for special sessions. The study

Table E.2: Citizen Involvement Checklist (Schwertz, 1979)

- ____ Bankers' Associations
- ____ Business Associations
- ____ Chamber of Commerce
- ____ Civic Organizations
  - ____ Jaycees
  - ____ League of Women Voters
  - ____ Others
- ____ Developer Associations
- ____ Elder Citizens' Organizations
- ____ Entrepreneurs
- ____ Executive and Professional Associations (local)
- ____ Farmers' Organizations
- ____ Fraternal Organizations
- ____ Labor Organizations
- ____ Neighborhood Associations
- ____ Neighboring Communities (where appropriate)
- ____ Newspaper Editors and Owners
- ____ Philanthropic Organizations and/or Foundations
- ____ Real Estate Brokers' Associations
- ____ Religious Organizations (By Denomination)
- ____ Retail Trade Associations
- ____ Service Organizations
  - ____ Rotary Club
  - ____ Others
- ____ Special Groups and/or Organizations
  - ____ Audubon Society
  - ____ Conservation Societies
  - ____ Historic Preservation Societies
  - ____ Sierra Clubs
  - ____ Others
- ____ Social Clubs
- ____ Trade Organizations
- ____ Utility Companies
- ____ Youth Organizations
- ____ Veterans' Organizations
- ____ Women's Auxiliaries
- ____ ____________________________
- ____ ____________________________
- ____ ____________________________
- ____ ____________________________
- ____ ____________________________
- ____ ____________________________

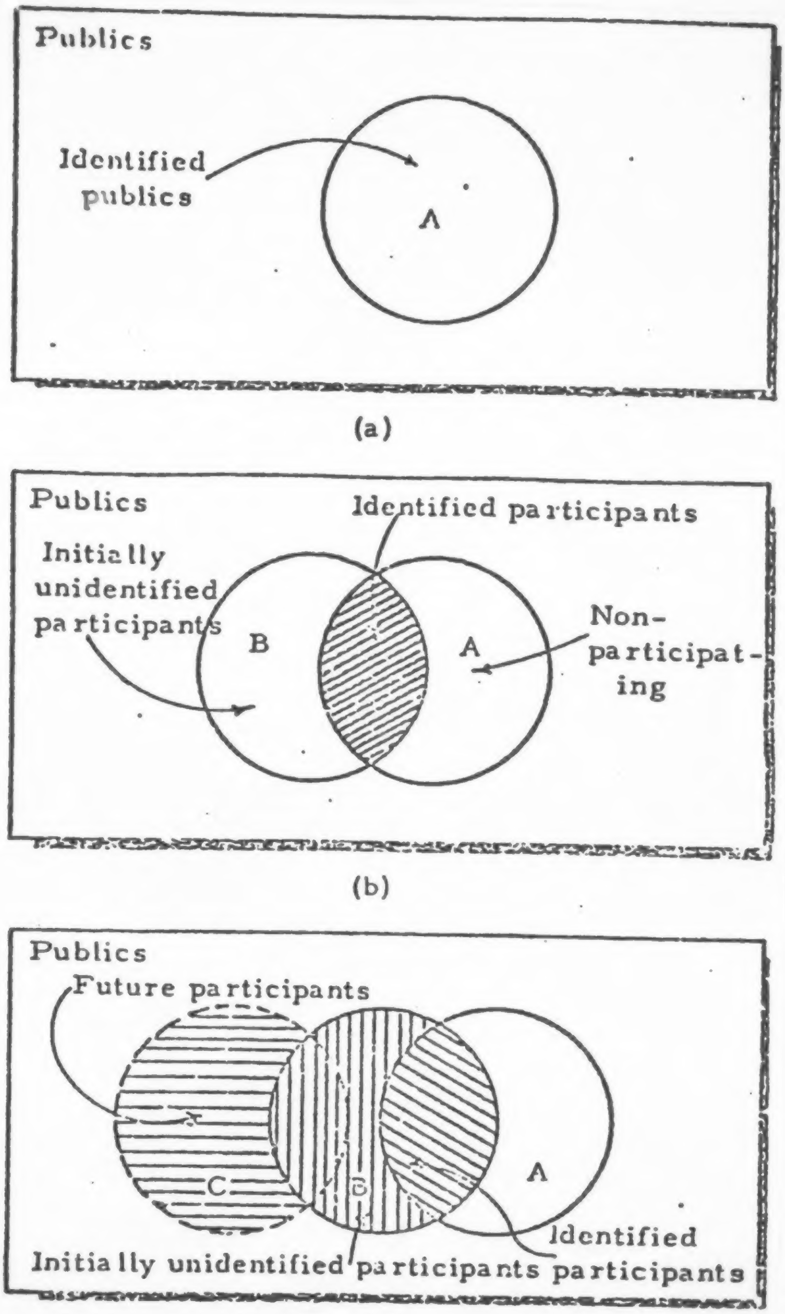
manager has no easy way to identify such interests; he must peruse the list and try to associate interests with organizational titles. This may be possible for organizations, but it is impossible for individuals -- unless they and their interests are well-known.

Bishop (1981) has developed a basic scheme for pragmatically identifying publics, with the concept shown in Table E.3. The list of interests/issues groups coincides with the earlier cited list of publics associated with water resources development projects (U.S. Army Corps of Engineers, 1971). Usage of Table E.3 requires the identification of the relation of each group (public) to the decision making process for an aquifer restoration project.

The planner must also be aware that identification of publics has the dimension of participation through time (Bishop, 1981). At the onset of planning, a certain segment of the public will have an interest in participating. These are usually people or groups that: (1) have participated in the past; (2) are affected by a problem; or (3) will be affected by a possible solution to the problem. Circle A in Figure E.6 (a) indicates this identified portion of the public. As planning progresses, some of those identified do not participate, while some previously unidentified publics will identify themselves. Circle B in Figure E.6 (b) illustrates those who are participating after the process has progressed for some time. Looking forward into time, there will always be those who may not be identified who may come into the process. This is shown by Circle C in Figure E.6 (c). Hence, the planner must be prepared to communicate with three sets of publics: (1) those that can be identified and will participate, (2) those that become identified as

Table E.3: Scheme for Identifying Publics (Bishop, 1981)

	Relation to the Study				
	Affected by the Problem		Affected by the Proposed Solution		Not Affected
	Directly	Indirectly	Users	Non-Users	
Interests/Issues Groups	Beneficial/Adverse	Etc.	...	...	
Individuals					
Property Owners/Users					
Conservation/Environmental Groups					
Sportsman's Groups					
Farm Organization					
Business/Industrial					
Professional					
Education Institutions					
Labor Unions					
Service Clubs					
State/Local Agencies					
Elected Officials					
News Media					


Publics
Identified publics
A
Publics
Identified participants
Initially unidentified participants
B
A
Non-participating
Publics
Future participants
C
B
A
Identified participants
Initially unidentified participants

(a)

(b)

(c)

Figure E.6: A Temporal Perspective of Identification of Publics (Bishop, 1981)

the process progresses, and (3) those that will be identified in the future. Thus, of the publics initially identified by the agency, some will follow through, others will drop out, and some previously unidentified interests will enter the arena of participation. Indeed, controversies in aquifer restoration projects have often occurred as a result of new participants entering at the end of the process in opposition to proposed actions. Three approaches can be used in dealing with the problem of public changing over time: (1) actively seek out and engage at the outset of a study a broad and representative range of public interests; (2) keep as much flexibility for as long in the process as possible, insofar as selecting a plan or recommending action; and (3) document the process and the public inputs relating to alternatives and issues studied (Bishop, 1981).

Selected Techniques for Communicating with Identified Publics

It was noted earlier that some techniques are better than others for communicating with different publics. Table E.4 summarizes the effectiveness of certain techniques for communicating with the publics identified earlier as associated with water resources projects (U.S. Army Corps of Engineers, 1971). Publics of the type listed in Table E.4 could also be expected to be associated with an aquifer restoration project.

SELECTION OF PUBLIC PARTICIPATION TECHNIQUES

A critical element in planning a public participation program is associated with the selection of public participation techniques to meet identified objectives and publics. It should be noted that there are

Table E.4: Effectiveness of Different Media on Various "Publics" (Bishop, 1975)

Publics	Public Hearings and Meetings	Printed Brochures	Radio Programs and News	TV Programs and News	Newspaper Articles	Magazine Articles	Direct Mail and Newsletters	Motion Picture Film	Slide-Tape Presentation	Telelecture
Individual Citizens	M	L	H	H	H	L	L	M	M	L
Sportsmen Groups	M	M	M	M	M	H	H	H	H	M
Conservation-Environment Groups	M	M	M	M	M	H	H	H	H	M
Farm Organizations	M	M	M	M	M	H	H	M	M	M
Property Owners and Users	M	L	H	H	H	L	L	M	M	L
Business-Industrial	L	L	M	M	M	M	H	M	M	L
Professional Groups and Organizations	L	L	M	M	M	M	H	M	M	L
Educational Institutions	M	L	L	L	M	M	H	M	M	M
Service Clubs and Civic Organizations	L	L	M	M	M	M	L	H	H	M
Labor Unions	L	L	M	M	M	L	L	M	M	L
State-Local Agencies	H	M	L	L	L	M	H	H	H	H
State-Local Elected Officials	H	M	L	L	L	L	H	H	H	H
Federal Agencies	H	M	L	L	L	L	H	M	M	M
Other Groups and Organizations	H	M	M	M	M	M	H	H	H	M

H = Highly Effective

M = Moderately Effective

L = Least Effective

numerous techniques, and a well-planned public participation program will probably involve the use of multiple techniques over the lifetime of an aquifer restoration study. The most traditional public participation technique is the public hearing, which is a formal meeting for which written statements are received and a transcript is kept. The public hearing is generally not the best forum for public participation in an aquifer restoration project. Several classification schemes have been developed for public participation techniques in accordance with their function (Schwertz, 1979) and communication characteristics and potential for meeting stated objectives (Bishop, 1975). In addition, Creighton (1981b) developed a short catalog of the advantages and disadvantages of several additional techniques. This section of this appendix will highlight the features of the classification schemes and the catalog.

Techniques Classification According to Function

Schwertz (1979) summarized a U.S. Department of Transportation (DOT) classification scheme for 37 public participation techniques grouped into six functional classes: (1) information dissemination; (2) information collection; (3) initiative planning; (4) reactive planning; (5) decision-making; and (6) participation process support. Table E.5 lists the 37 citizen participation techniques by the functional classes (Schwertz, 1979). Volume II of the DOT report describes the 37 techniques using the following format: description; positive features; negative features; potential for resolving issues; program utilization; costs; and bibliography (U.S. Department of Transportation, 1976).

Table E.5: Participation Techniques Classified by Function (Schwertz, 1979)

---

1. INFORMATION DISSEMINATION
    - Public Information Programs
    - Drop-In Centers
    - Hot Lines
    - Meetings - Open Information
2. INFORMATION COLLECTION
    - Surveys
    - Focused Group Discussions
    - Delphi
    - Community-Sponsored Meetings
    - Public Hearings
    - Ombudsman
3. INITIATIVE PLANNING
    - Advocacy Planning
    - Charrettes
    - Community Planning Centers
    - Computer-Based Techniques
    - Design-In and Color Mapping
    - Plural Planning
    - Task Force
    - Workshops
4. REACTIVE PLANNING
    - Citizen's Advisory Committees
    - Citizen Representatives on Policy-Making Boards
    - Fishbowl Planning
    - Interactive Cable TV-Based Participation
    - Meetings - Neighborhood
    - Neighborhood Planning Councils
    - Policy Capturing
    - Value Analysis
5. DECISIONMAKING
    - Arbitrative and Mediative Planning
    - Citizen Referendum
    - Citizen Review Board
    - Media-Based Issue Balloting
6. PARTICIPATION PROCESS SUPPORT
    - Citizen Employment
    - Citizen Honoria
    - Citizen Training
    - Community Technical Assistance
    - Coordinator or Coordinator/Catalyst
    - Game Simulation
    - Group Dynamics

Summary comments relative to the six functional classes are as follows (Schwertz, 1979):

(1) Information Dissemination techniques are used to inform the public of actions being taken in an area, the opportunities for citizen input, and any proposed plans that have been submitted. The flow of information is characteristically one-way. Accordingly, mass media techniques are most frequently used for this purpose. Many local governments have established Public Information Programs for coordinating information dissemination. The most frequently used mass media technique is the local daily newspaper. Where a local daily newspaper is not published, many communities will use the services of neighboring larger communities. Many smaller communities prepare newsletters and posters for disseminating information on meeting dates and proposed plans to supplement out-of-town newspapers. The use of radio and television is also common in Public Information Programs. In larger communities, television documentary films are often found. Radio talk shows are utilized in all communities to assist in "getting the word out" about local growth management programs. Another useful technique for disseminating information is Open Information Meetings. They are particularly effective when used early in the planning phases of the local growth management program. Widely publicized, and open to all interested parties, the Open Information Meetings present technical information, planning proposals, or details about a specific work program or aquifer restoration project.

(2) Information Collection techniques are used to gather both technical data as well as opinion-related information. The two most frequently used techniques are the Public Hearing and the Survey. The Public Hearing has been used by almost every community at one time or another. Although the Public Hearing does permit the parties-at-interest to be heard, it does not permit a two-way communication between the agency representatives holding the hearing and the individual parties-at-interest. The normal sequence of a Public Hearing begins with a presentation by the sponsoring public agency followed by testimony of individuals recognized by the presiding agency officer. Therefore, the Public Hearing can, at times, become heated as parties-at-interest seek to assert their position. A less frequently utilized information collection technique is the Survey. However, as communities strive harder to ascertain the needs, attitudes, and opinions of its citizens, the use of the Survey becomes more prevalent. An advantage of the Survey over the Public Hearing is the ability to reach all segments of the population if it is properly administered. Public Hearings attract only the "vocal minority" and the parties-at-interest. Accordingly, a

properly administered survey can provide the community with the information it will require on needs, attitudes, and opinions to develop a responsible growth management program. Proper administration includes the use of mailed survey questionnaires, telephone interviews, and personal interviews. Sole reliance on mailed questionnaires will not yield results representative of all segments of the population. Telephone and personal interviews may be needed in addition to using mailed surveys.

(3) Initiative Planning techniques assign the responsibility for producing conceptual proposals and plans to citizen representatives. The most frequently used techniques have been Task Force committees and Workshops. Although the citizen committee is responsible for producing the conceptual proposals and/or plans, it often requires significant financial resources and local staff assistance to complete its tasks. Therefore, Initiative Planning techniques should be used by communities which possess sufficient financial resources and the trained staff to provide technical assistance as needed. A Task Force is an ad hoc citizen committee in which the parties-at-interest are actively engaged in a well-defined problem solving or specific task effort in the planning process. In most larger communities, particularly those over 50,000 in population, Task Force techniques have been used to obtain citizen involvement. Workshops are working sessions lasting anywhere from several hours to several days. They are held to enable parties-at-interest to engage in mutual education by thoroughly discussing a technical issue or idea and by trying to reach some basic understanding about its nature, relevance, and role in the particular proposal, project, or plan. The workshops are frequently directed by trained professionals and involve citizens alone or together with local staff and elected officials. Although workshops promote the achievement of a consensus and the introduction of alternative viewpoints among those citizens, when used as the sole citizen participation technique the problem of non-representation of all citizen segments arises. (It should be also noted that the same is true of using Task Force committees as the sole citizen participation technique in a community.)

(4) Reactive Planning techniques assign the responsibility for producing conceptual proposals and plans to the local planning agency, and citizens are asked to react to those proposals and plans. Based on citizen input, the conceptual proposals or plans are revised and resubmitted for reaction. Two of the most frequently utilized Reactive Planning techniques are the Citizens' Advisory Committees and the Neighborhood Planning Council. Citizens' Advisory Committees consist of a group of citizens called together by a local agency to represent their

community and advise the local agency on specific projects or programs. They have limited advisory powers, are often large in membership (50 to 100), and tend to meet infrequently. Often the life of the committee is tied to the specific project for which they are to provide advice. Citizens' Advisory Committees are prevalent in communities of every size. If used properly, and if the members are representative of the community, this technique can serve as a community listening post and also serve to relay technical proposals and plans to the public.

(5) Decision-making techniques are not feasible in program areas where the responsibility for the decision is mandated to elected officials. However, the Citizen Referendum is the decision-making technique which has received the greatest use in the past.

(6) Participation Process Support techniques are not citizen participation techniques in themselves, but mechanisms to strengthen the effectiveness of the other techniques. For example, Citizen Training can be provided to assist citizen members of boards or committees with the technical aspects of the issues with which they are confronted. Citizen Honoraria can assist citizen members with the expenses incurred in serving on boards or committees. Group Dynamics can facilitate group interaction and achievement of group goals among Task Force members or Workshop participants.

Techniques Classification According to Communication Characteristics and Potential for Meeting Stated Objectives

Bishop (1975) developed a structured classification scheme for 24 public participation techniques. Table E.6 displays the techniques in three groups: (1) the first 6-listed techniques represent public forums; (2) the following 11-listed techniques represent community contacts; and (3) the final 7-listed techniques represent interactive group methods. The communication characteristics of the 24 techniques are displayed in Table E.6 in terms of the level of public contact achieved, ability to handle specific interest, and degree of two-way communication. A relative scale of low (L), medium (M), and high (H) effectiveness is used to delineate the communication characteristics of

Table E.6: Capabilities of Public Participation Techniques (Bishop, 1975)

Communication characteristics				Impact assessment objectives					
Level of public contact achieved	Ability to handle specific interest	Degree of two-way communication	Public participation techniques	Inform/ educate	Identify problems/ values	Get ideas/ solve problems	Feedback	Evaluate	Resolve conflict/ consensus
M	L *	L	Public hearings		X		X		
M	L	M	Public meetings	X	X		X		
L	M	H	Informal small group meetings	X	X	X	X	X	X
M	L	M	General public information meetings	X					
L	M	M	Presentations to community organization	X	X		X		
L	H	H	Information coordination seminars	X			X		
L	M	L	Operating field offices		X	X	X	X	
L	H	H	Local planning visits		X		X	X	
L	H	L	Planning brochures and workbooks	X		X	X	X	
M	M	L	Information brochures and pamphlets	X					
L	H	H	Field trips and site visits	X	X				
H	L	M	Public displays	X		X	X		
M	L	M	Model demonstration projects	X			X	X	X
H	L	L	Material for mass media	X					
L	H	M	Response to public inquiries	X					
H	L	L	Press releases inviting comments	X			X		
L	H	L	Letter requests for comments			X	X		
L	H	H	Workshops		X	X	X	X	X
L	H	H	Charettes			X		X	X
L	H	H	Advisory committees		X	X	X	X	
L	H	H	Task forces		X	X		X	
L	H	H	Employment of community residents		X	X			X
L	H	H	Community interest advocates			X		X	X
L	H	H	Ombudsmen or representative		X	X	X	X	X

* L,low; M, medium; H, high

the 24 techniques. Table E.6 also has information on the potential usefulness of each technique relative to meeting one or more of six objectives for public participation in the decision making process. Specific comments on the advantages and limitations of certain listed techniques are as follows (Bishop, 1975):

(1) Public hearings -- Public hearings still tend to be formal and rather highly structured. However, there seems to be a trend away from this formality while still maintaining appropriate records, that is, the transcript and written statements for the hearing record. Because of the cost and delay in developing the hearing record, public hearings should generally be used only at stages in the decision making process where a formal record or transcript is required. This is not to say that public hearings do not serve an important function. Although the hearing is more costly and formalized it provides an opportunity for any agency, group or individual to be on permanent public record as having put forth a certain view. In fact, in view of many publics, the hearing, because it has a high degree of legitimacy, is the one place their voice must be heard. This single fact should not be overlooked when considering the virtues of the public hearing. Although hearings have a major advantage in public acceptance there are disadvantages; for example, public hearings provide no guarantee of representativeness; and thus there is a high potential for bias. The chairman, being from the agency, may also strongly bias the hearing. Open ended statements presented are often hard to interpret and use in planning, and often persons testifying do not completely understand the issue or the plan on which they are speaking.

(2) Public meetings -- The public meeting is less formalized than are hearings and do not require a transcript. However, detailed notes should be kept on file and recorded. These meetings, like the public hearing, provide the opportunity for participation by a wide cross section of the public. Although the tone here is informality, a discussion leader or chairman must maintain control over the meeting to prevent polarization of positions and to keep the meeting on the main issues and topics of discussion. Public meetings seem to have most of the advantages of the hearing without the rigidity and formality and the problems of cost of permanent records. This point becomes significant when a number of meetings are necessary in the decision making process. In keeping with the public meeting's less formal and rigid structure, physical details such as placing the agency staff on the audience level and less formal seating of the audience itself should be used.

This applies to meeting organization as well. After the opening statements by the chairman, the meeting can be turned over to the study manager. This tends to give the public the feeling that they are more intimately involved with the study as opposed to upper level staff. For purposes of efficiency this type of forum could often supplant the original hearing concept.

(3) Informal small group meetings -- While this type of meeting may take several forms and serve several purposes, the overall format is much the same as a public meeting. In this respect, small group meetings may function as a series of small scale public meetings to allow more intimate contact with publics from various geographic or interest group areas. General community meetings may be of this sort. Meetings of general interest may be advertised by public notice while others will perhaps be invitational if a particular specialized discussion with key individuals or community leaders is to be held. The basic idea of this meeting, as with large scale forums, is to present information and to ascertain the needs, desires, and opinions of the affected or interested public. The format should emphasize informality to the point of a round table type of discussion if feasible. Again, a discussion leader, preferably the project manager, should exercise a controlling function to prevent community or local factions from polarizing the meeting.

(4) Information and coordination seminars -- This technique is not used to inform the general public directly, but functions to inform and coordinate with special interest groups, specific individuals and groups representing segments of the public. Often public interests and needs are voiced through key individuals, elected officials and non-elected leaders, rather than by involvement of the general public. Seminars could be effectively used with community and group leaders, public agencies or officials, and special interest groups. Individual citizens in an aquifer restoration project area might be a special interest group. Seminars are an excellent way of keeping elected officials up-to-date on a regular basis, providing specialized information to interest groups and clarifying policy and plans to any group or agency. These seminars could also aid in developing coordination between cooperating agencies. Seminars can be used as one technique for advanced preparation for workshops and special committees. This is an efficient method of providing select personnel with information necessary to perform a prearranged future function. A major advantage to the seminars is that they have a low time budget. They can be organized on a regularly scheduled basis or only when needed.

(5) Forum of other agencies or groups -- Forums of other agencies and groups such as civic group meetings, organization meetings, etc., can also be used for pertinent presentations or statements. These regularly scheduled meetings are an effective avenue for broadening contact during the planning process. Equally important is the opportunity to clarify policy and positions not only to the agency or group, but often directly to their constituency or organization as well. This approach should be utilized to the maximum extent possible by notifying potential audiences of the agencies' availability to provide pertinent information and discussion programs.

(6) Operating field offices -- This serves a more or less specialized liaison function between the agency office and the public. In studies necessitating close local contact and coordination it may be used efficiently, particularly if well publicized. The field office can serve a planning study function and also be geared to providing public information. Duration of operation will depend on study planning and information needs. The field office could be of particular value in a controversial study in which the planning office, by virtue of distance or other limiting factors, is not readily accessable.

(7) Local planning visits -- Community or on-site visits are oriented toward increased understanding and coordination with cooperating agencies, knowledgeable community interest groups, and individuals. The technique should serve a professional function rather than public relations. These visits can have the secondary function of providing advice on community or area problems related to the study. Visits should be tuned to community needs or specific aspects of the study. A practical example of the value of local visits would be liaison work or advance preparation for workshops. The press can often be usefully included in planning visits.

(8) Field trips and site visits -- These differ from planning visits in that they are primarily non-professional "show-me" trips. These visits can be used to accurately inform public groups, local officials, and the media about the specifics of an aquifer restoration plan. Trips can be combined with or considered as field press conferences. In this fashion, the public is informed indirectly through their representatives -- either groups or media. This is also excellent advance preparation for an open workshop or a later hearing.

(9) Public displays and model demonstrations -- Under appropriate conditions, displays and demonstrations can provide an overview of an aquifer restoration project, quick appraisal of alternatives, description of impacts of the project, and

information on any number of project-related issues. The critical factor in good use of public displays seem to be their location and manning. Certainly the best locations are areas of high public use or areas where particular affected publics may be contacted. Displays may take several forms ranging from a manned project model to an automated slide show. Model demonstrations may be used as a public dispay or may be considered as an instructional aid at any type of public forum, workshop, or seminar. Displays or demonstrations, to be effective, must be clear, concise and directly related to areas of experience and familiarity of the publics.

(10) Workshops -- The success of workshops depends, in large part, on the degree of advance preparation; therefore, this should be as comprehensive as possible. Advance preparation for workshops might include distribution of the various types of brochures, planning visits, coverage by the media and direct contact of interested parties. Workshops can be several types depending on the planning activity and stage of the decision making process, the publics to be contacted, and the subject matter for discussion.

(a) Open public workshop -- This type of workshop, in practice, is the most common. However, one major disadvantage of the open workshops is the uncertainty in the number of people that will attend, and their interests. With large numbers there is more limited opportunity for discussion and the high degree of interaction that is desired in a workshop.

(b) Invitational workshop -- As implied by the name, invitational workshops are geared toward particular individuals and groups and around issues or alternatives that are somewhat specific in nature. This type of workshop has the advantage of being highly interactive, involving only interested publics on specific, critical issues.

(c) Invitational/Open -- This workshop approach, a combination of the first two, provides a means of bringing all concerned publics into the planning process and providing a productive interchange. The workshop is structured to focus the beginning discussion with an invited group of interests, for example, a panel, then opening the meeting up to the general public.

There are, of course, several modifications to these three workshop types that can be introduced. Several varieties of mini-workshops are proving to be effective in stimulating interaction. Publics attending a workshop can be divided into small discussion groups, each with a leader, to exchange ideas on different subjects. Under certain circumstances revolving groups can be instituted, where individuals spend a set amount of time on one issue or subject, and then break-up with each individual going to a different group. As with all workshops, but especially the revolving mini-type, adequate pre-workshop preparation is a necessity.

(11) Charettes -- The charette functions as a highly intense, resolution-oriented meeting. It can be thought of as a "mini" workshop or small select group meeting with the express purpose of reaching a decision or resolving a conflict. The charette goes beyond the interaction levels of an ordinary workshop and is problem solving and decision oriented in its subject matter. Hence, it presupposes a certain amount of advance preparation to assure a thorough understanding of the subject and a common ground on which to begin. Charettes can function at the interagency level, or community level, with special interest groups. In this setting the planner is often a negotiator of community interests. The intensity of charette sessions are certainly not necessary in all aquifer restoration studies, but in certain cases resolution and/or decision comes only through this type of interactive situation.

(12) Special committees -- Several types of citizens committees have been used in planning studies. Committees, as representative public bodies, can serve a very useful purpose in aquifer restoration studies, but the overall concept must be well considered before the planner can effectively utilize the committee approach. Types of committees that have functioned in planning studies are the following:

(a) Citizens advisory committee -- The concept of an advisory committee has recently been receiving criticism concerning its role in the planning process. The major question with the role of the CAC is that perhaps it was never advisory and indeed it should not be. It is extremely difficult to determine the extent of the public interests that a committee's advice or actions may represent. Since a committee with a true advisory capacity is difficult to staff with people representing a broad range of community interests as well as expertise pertinent to the aquifer restoration study, this type of committee often ends up serving a limited or issue specific function. However, a committee that is broadly representative can be extremely useful as a sounding board for study proposals.

(b) Ad hoc task force/committee -- Aquifer restoration problems of a technical or local nature can often be effectively approached by a committee or task force which works towards solutions and advises the planning agency of local preferences on those particular study problems. A committee or task force should be limited to consideration of special problems. When controversial aspects of a plan are involved, a group representing all sides of the issue is necessary for lasting conflict resolution or problem solution. Since both ad hoc committees and special task forces are set up to work on a particular problem area, they should be dissolved once a solution has been rendered.

(c) Citizens committees -- A new trend in committee roles in the planning process is that of the non-advisory, non-debating forum. The task of a citizens committee is threefold: (1) to provide fact-supported suggestions or arguments on various problems or issues that might arise; (2) to act as a sounding board to reflect community or sub-regional interests and preferences in regard to issues, alternatives or problems which will arise during the course of the decision making process; and (3) to act as a catalyst for the expansion of public participation by utilizing other techniques (workshops, small group meetings, etc.); to involve the committee member's constituency by hosting and participating in various public forums; and to bring other participants into the planning process.

The success or failure of citizens committees seems to hinge on selection of committee members and timing. Selection of members often becomes the responsibility of the agency, but organizations or local officials should be invited to designate members, or at least suggest names. Representatives from certain major groups must be included from the very beginning, with additions or changes being a function of the committee or the supporting organizations. Committees are often unproductive because they are initiated too late in the decision making process. In this situation, members feel they are little more than a token gesture and can contribute nothing that will influence what has already been determined. On the other extreme, beginning too early when the members have nothing on which to work may result in apathy and dissolution of the committee. The citizens committee can be an effective tool for public involvement in decision making. Unfortunately, however, there are some major difficulties that have prevented its widespread acceptance. First and foremost of these is the time commitment required of the planners and the participants. The planner usually must spend a great deal of his time organizing and participating in committee

> functions. The committee members, if they take their task seriously, can also devote a considerable amount of time to the committee. Considering these factors individual citizens committees, on the average, may not have a long life expectancy. In studies where there is not a considerable degree of opposition and interest, apathy takes its toll. This is not to discourage the planner from utilizing citizens committees. On the contrary, they can be one of the better participation tools available. However, it is only realistic to be aware of the disadvantages.

Due to the growing importance of citizen committees in public participation programs, some additional relevant information from Creighton and Delli Priscoli (1981) will be highlighted. They indicated that a citizen's committee can provide a number of helpful functions in the decision making process, including:

(1) Help set planning priorities.

(2) Review technical data and make recommendations on its adequacy.

(3) Help resolve conflicts among various interests.

(4) Help in the design and evaluation of the public involvement program.

(5) Serve as a communication link to other groups and agencies and bring reactions back to the agency.

(6) Review and make recommendations on the decision making process.

(7) Assist in developing and evaluating alternatives.

(8) Help select consultants and review contracts.

(9) Review and make recommendations on the program budget.

(10) Review written material prior to release to the general public.

(11) Help host and participate in public meetings.

(12) Assist in educating the public about the project and the decision making process.

Creighton and Delli Priscoli (1981) delineated the following four general principles for establishing citizens' committees:

(1) Clearly define the limits of authority of the citizen's committee. It is extremely important that the authority of the citizens' committee be defined as there is frequent confusion as to the difference between a group that is an advisory and a decision-making body. It is easier for a citizens' committee to cope with limits to their authorities if they are clearly defined at the beginning of the study. If expectations are created of greater authority than actually exists, the sense of betrayal is often greater than if there had been clearly defined limits in the first place.

(2) Citizens' committees must be representative of the full range of values within the community. A citizens' committee that represents only a few limited viewpoints may mislead the agency and embitter those publics who are not included in the committee. Typically, citizens' committees are large enough so that it is possible to have direct representation for all the different viewpoints. Every effort must be made to insure that the citizens' committee represents the full spectrum of values within the community.

(3) The life of the committee should be limited. The longer that a committee is in existence, the more likely it is that the members of the committee become unrepresentative of their constituencies and instead become a new kind of elite. As a result it is important to establish from the beginning what the life of the committee will be. Typically, the life of the committee coincides with some major function such as the selection of the aquifer restoration strategy.

(4) Efforts should be made to insure that members of citizens' committees maintain regular communication with the constituencies they are supposed to represent. As suggested above, citizens' committees tend over time to become a new kind of elite, and unless the expectation is established from the beginning that one of the duties of citizen committee members is to maintain communication with their constituencies, then the membership may become increasingly unrepresentative of the public at large. This communication with their constituencies could take the form of briefings of the groups they represent on study progress, informing their constituencies through their own organizational newsletters, or occasional interviews with other leaders from their constituencies.

The biggest single problem in establishing a citizens' committee is to select members in such a way that the public believes the committee represents the community (Creighton and Delli Priscoli, 1981). Because an attitude of suspicion often exists towards the agency, there are frequent accusations that agencies have established citizens' committees in such a way that they were "stacked" towards the desired ends of the agency. There are five basic strategies by which members of a citizens' committee can be selected:

(1) Members are selected by the agency with an effort to balance the different interests. As mentioned above, this runs the risk of the public believing that the agency has established the committee to serve the agency's purposes. This danger can be reduced somewhat if the agency has consulted thoroughly with various other governmental agencies and interest groups prior to making these selections and the selections clearly encompass many of these recommendations.

(2) The agency may turn over the selection of the citizens' committee to some third party or group. One approach is to have some local elected body such as a city council or board of supervisors select the membership. An alternative approach is for the agency to select a small committee and permit the committee to select a pre-determined number of additional members. In either of these cases, it is extremely important that the agency communicate its expectations that the membership of the committee should reflect the entire range of values within the community.

(3) An alternative method is for the agency to identify the interests it wishes to have represented and allow the various groups within those interests to select their own representatives. This can create administrative problems as volunteer groups sometimes have difficulty coordinating between themselves to select a representative, but it does eliminate the risk that the agency will be seen as "stacking the deck".

(4) It is also possible to use any of the three methods above and then augment the membership with the addition of volunteers. This in effect allows the different interests to adjust the membership of the group by obtaining volunteers from their own ranks. But if votes are being taken, it does lead to the risk

that various groups will "stack the decks" by trying to add a large number of additional volunteers.

(5) In a few cases, membership on a citizens' committee has been determined by popular election. This last technique has been utilized only on projects where the target publics are clearly identified and limited.

Catalog of Additional Techniques

Creighton (1981b) prepared a short catalog of public involvement techniques. Within the catalog a short description is provided for each technique plus a discussion of relevant advantages and disadvantages. Techniques not previously discussed will be presented herein, including interviews; hotlines; newspaper inserts; reports, brochures, and information bulletins; surveys and questionnaires; participatory television; cumulative brochures; mediation; Delphi; and simulation games. Summary information related to these techniques is as follows (Creighton, 1981b):

(1) Interviews -- One technique for quickly assessing public sentiment is to conduct a series of interviews with key individuals representing the range of publics most likely to be interested or affected by the decision making process. The kinds of information which might be discussed in an interview would include the amount of interest in the aquifer restoration study, the goals and values of the interest group the individual represents, the manner in which the interest group would like to participate in the study, political climate and relationship between the various interest groups. Interviews can either be non-structured, or the interviewer can prepare a list of questions or topics to be discussed in each interview, so that responses can be easily compared and summarized. Since there are skills involved in effective interviewing, interviews should be conducted by persons with experience or training in interviewing. Federal agencies are required to get approval from the Office of Management and Budget for all surveys and questionnaires. Structured interviews may fall under these approval requirements, so Federal agencies may find it preferable to stay with unstructured interviews.

(a) Advantages of Interviews: Interviews can provide a quick picture of the political situation in which an aquifer restoration study will be conducted. Interviews can provide important information about how various interests wish to participate. Personal relationships can be built with key individuals and more direct communication links established with the publics. Once communication has been established through an interview, individuals and groups are more likely to participate.

(b) Disadvantages: Poor interviewing can create a negative impression of the individual and the agency. Interviews may not be entirely representative of public sentiment.

(2) Hotline -- A hotline is an "easy to remember" telephone number which is publicized through repetition in brochures, reports, news stories, paid advertising, etc., as a single telephone number that citizens can call to ask questions or make comments about project-related issues. If the public which the agency wishes to reach is large geographically, the hotline is usually established so that the call is toll-free to the public regardless of where the call is placed. The hotline is manned with staff who will take responsibility for finding answers to questions from the public, or for relaying comments or complaints from the public to appropriate staff persons. Hotlines have been used as a method of handling public complaints, and as coordination points for individuals requiring information about the progress of a study. Comments received over a hotline can be incorporated as part of the record of a public meeting or hearing.

(a) Advantages of the Hotline: The hotline provides a convenient means by which citizens can participate in the study. The hotline assists citizens in locating the staff most likely to be able to answer their questions or receive their comments. The hotline may be a useful means of providing information about meetings or other public involvement activities. The hotline is a communication to the public of the sponsoring agency's interest in their comments or questions.

(b) Disadvantages of the Hotline: Defensive or insensitive comments may produce a negative reaction from the public. The hotline must be staffed by people able and willing to deal with public comment effectively.

(3) Newspaper Inserts -- One technique which has been used to provide information to the broad general public and, at the same time solicit comment back from the public, is a newspaper insert including a response form distributed through the local newspaper. Most newspapers are able to handle the

distribution of inserts for a modest cost, and are often able to print the insert at considerably less cost than other commercial printers. The newspaper insert can describe the aquifer restoration study and decision making process and the various means by which the public can be involved; it can also include a response form which will allow people to express opinions or indicate their willingness to be involved in other public involvement techniques. Most urban newspapers are able to distribute inserts to selected geographical areas, rather than their entire readership, so that it is possible to target the insert at those areas which will have the highest interest in the study. On a percentage basis, the return of response forms is not likely to be very high, although on a total quantity basis, it may provide a means of participation for the largest number of citizens compared with other public involvement techniques. Because respondents are self-selecting, a statistical bias is introduced into the responses, so that they cannot be represented as statistically valid like a survey.

(a) Advantages of a Newspaper Insert: Newspaper inserts reach a much greater percentage of the population than most other public information techniques. The inserts provide an opportunity for a large number of citizens to participate. Newspaper insert response forms provide a means for identifying other individuals and groups interested in participating in public involvement activities.

(b) Disadvantages of Newspaper Inserts: Newspaper inserts are relatively expensive to produce and distribute in large numbers. The response rate from newspaper inserts is relatively low, and it cannot be represented as statistically valid.

(4) Reports, Brochures, and Information Bulletins -- Reports, brochures, and information bulletins are an essential part of every public involvement effort. They are an essential vehicle for informing the public of the opportunities for participation, the progress of the study to date, and any decisions that have been made. There are three times at which reports are typically published in a public involvement program. These include: after problem definition and issues identification, including initial data collection; upon identification of a set of general alternatives; and upon identification of specific detailed alternatives and their environmental consequences and costs. Because reports contain technical information, one key requirement is to write reports in a manner which provides needed technical information, yet is understandable to the general public. It is sometimes useful to have reports reviewed by an advisory committee who

can point out confusing, biased, or unnecessary material in the report.

Brochures are usually brief (up to sixteen pages) and contain a description of the study, the issues involved in the study, and a summary of the opportunities for the public to participate in the study. Typically, brochures are used to reach new publics or inform known publics of the initiation of the study. The usefulness of a brochure is almost entirely dependent on its visual attractiveness and the skill with which it is written.

Information bulletins or newsletters are periodic reports to the public published as a means of maintaining a continuing interest in the study as well as documenting the progress in the study in a highly visible manner for the public. Information bulletins or newsletters are particularly important during portions of the study which are relatively technical in nature. During these periods the general public is less likely to be involved but should be kept informed of what is occurring through these media. The value of an information bulletin or newsletter rests almost entirely upon its ability to stir interest and encourage interaction. A drab, boring, bureaucratic sounding newsletter will usually not be worth the effort.

(a) Advantages of Publications: Publications are direct means of providing a substantial amount of information to a large number of people in a relatively economic manner. Publications are able to communicate a greater amount of information than almost any other form of communication. Publications serve as a permanent record of what has transpired in the public involvement program.

(b) Disadvantages of Publications: Preparation of attractive publications requires definite skills which are not available in all organizations, so may have to be purchased outside the organization. Because of cost factors publications still reach only a limited audience and cannot be considered the only means by which to inform and involve the general public.

(5) Conduct a Survey -- Surveys are an effort to determine public attitudes, values, perceptions on various issues employing a rigorous methodology to insure that the findings of the survey in fact represent the sentiment of the community being sampled. Surveys can be conducted by phone, by mail, by individual interviews, or in small group interviews. Firms that design surveys spend many hours and utilize complex procedures to insure that the survey does not contain bias and that the "sample" of people interviewed is in fact

representative. As a result surveys must be designed and conducted by persons experienced in survey design. Normally this means that someone outside the planning organization must be retained to design and conduct the survey. Federal regulations require OMB approval of all surveys or formal questionnaires conducted by Federal agencies or with Federal funds. These approvals are very difficult and time-consuming to obtain, virtually ruling this technique out for most Federal agencies.

(a) Advantages of a Survey: Surveys can provide an expression of feeling from the total public, not just those publics which are most directly affected. Surveys can provide an indication of whether or not the active participants in a public involvement program are in fact representative of the broader public.

(b) Disadvantages of the Survey: Unless surveys are carefully designed, they do not produce reliable and meaningful data. The cost of developing statistically reliable surveys is high. Surveys cannot substitute for political negotiation between significant interests.

(6) Participatory Television -- Because of the number of people reached by television, it holds considerable potential as a tool for both informing the public, and soliciting participation. Some experts see cable television as holding the answer to participation, since eventually cable television may be utilized in such a way that it allows for two-way communication. In the meantime, there have been several major uses of television programs. These include:

(a) Preparation of a half-hour or a one-hour television program describing alternative courses of action in a major study. Participants are asked to express their preference by mail or by a ballot that has been distributed in advance of the television program. In some cases discussion groups have been organized so that people watch the television program as a group, and discuss the program as a group, before marking the ballots.

(b) The agency could also obtain a block of time and conduct a call-in show on issues. One planning agency conducted a television program much like a tele-thon, with banks of telephone operators to receive calls from the public and have them answered by a panel of elected officials.

Although television reaches large numbers of people, it is unusual to be able to obtain sufficiently large blocks of time for a participatory television program on commercial television, although this has been accomplished in a few cases where the study was extremely controversial. The audience on educational, university or cable television is much smaller and something of an educational and social economic elite. This creates problems of representation. Any poll which is taken accompanying such a program would share these problems of representation.

(a) Advantages of Participatory Television: Participatory television reaches the largest audience of any community involvement technique. This technique is most convenient for the participants, because they do not have to leave their own home. Even if people do not participate by filling out a ballot or phoning in, there is a definite education function to participatory television.

(b) Disadvantages of Participatory Television: The audience viewing the program may not be representative, and any votes or tallies taken as a result of the program may also be unrepresentative. Unless some participation occurs in designing the program, the public may not feel that the agency accurately or objectively described the issues. This kind of participation gives equal value to somebody who lives immediately near a problem as somebody who lives fifty miles away and is only peripherally affected.

(7) Cumulative Brochure -- The cumulative brochure is a document which keeps a visible record of a series of repetitive public meetings, public brochures, workshops, and citizen committee meetings. At the beginning of the process, a brochure is prepared presenting various study alternatives along with the pros and cons for each of the alternatives. In a series of public meetings and workshops, individuals, agencies, and organizations are invited to submit their own alternatives which are then included in the brochure along with their descriptions of pros, cons, and a no-action alternative. The brochure is then republished with space provided in the brochure for individuals to react to the various alternatives by writing their own pros and cons. These comments then become a part of the new brochure. With each round of meetings or other forums for public comment, the brochure grows by the addition of the public comment and technical response. The final document is quite thick, but does provide a visible record of the entire process.

(a) Advantages of a Cumulative Brochure: The process is very visible and allows the public to see how a decision was reached. The process encourages open communication between the various publics as well as between the public and the sponsoring agency. No special status is granted to any one individual or group over another.

(b) Disadvantages of the Cumulative Brochure: The final brochure is a large, cumbersome document and the many editions of the brochure can be expensive to produce. The effectiveness of the brochure depends on the ability of the sponsoring agency to address the issues in non-bureaucratic language. The format of the brochure forces public reaction into a pro or con response when there may be other positions as well. Since the sponsoring agency prepares the brochure, groups which are suspicious of that agency may question whether the brochure is biased.

(8) Mediation -- Mediation is the application of principles of labor/management mediation to environmental or political issues. In mediation a group is established which represents all major interests which will be affected by a decision. Members of the mediation panel are all "official" representatives of the interests, and are appointed with the understanding that the organizations they represent will have the opportunity to approve or disapprove any agreements which result from the mediation. The basic ground rule which is established is that all agreements will be made by unanimity. A key element in mediation is the appointment of a third party mediator -- someone skilled in mediation, who is not seen as an interested party to the negotiations. The mediator not only structures the deliberations, but often serves as a conduit for negotiations between the various parties. Mediation is only possible when the various interests in a conflict believe they can accomplish more by negotiation than by continuing to fight. Additional information on mediation will be provided later in this appendix.

(a) Advantages of Mediation: Mediation can result in an agreement which is supported by all parties to the conflict. Mediation may lead to quick resolution of issues which might otherwise be dragged out through litigation or other political processes.

(b) Disadvantages of Mediation: Mediation is an entirely voluntary process, so it will work only when all parties are willing to negotiate. Mediation requires a highly skilled third party mediator.

(9) Delphi -- The Delphi process is a method for obtaining consensus on forecasts by a group of experts. It can be used as a technique for estimating possible environmental improvements of various aquifer restoration actions. The basic procedure is as follows. A questionnaire is submitted individually to each participant requesting them to indicate

their forecasts concerning the topic. The responses to the questionnaire are consolidated and resubmitted to the participants with a request that they make an estimate of the probable occurrence of each event. The participants' responses are again collected and a statistical summary is prepared. The statistical summary is distributed to all participants and the participants are asked to give a new estimate now that they have seen the response of the total group. Participants whose answers differ substantially from the rest of the group are asked to state the reasons behind their answers. The new responses are then summarized statistically and redistributed to the participants who are asked to prepare a final estimate. A final statistical summary is then prepared based on participants' comments.

(a) Advantages of a Delphi Process: The Delphi process is an effective tool for achieving a consensus on forecasts among groups of experts. Delphi minimizes the disadvantages of group dynamics such as over-dominance by a single personality or positions taken to obtain status or acceptance from the group.

(b) Disadvantages of a Delphi Process: Delphi may have a tendency to homogenize points of view. The process of mailing questionnaires and redistributing summaries can be a time-consuming and cumbersome process. The public may be no more willing to accept the findings of an expert panel than it would of a single technical expert. The experts still may not be right.

(10) Simulation Games -- There have been a number of simulation games which have been designed to allow people to simulate the effects of making particular policy choices and decisions, and in that process learn more about the impact of decisions and the interrelatedness of various features of an environmental or economic system. Simulation gaming provides an opportunity for people to try out their positions, and see what the consequences would be and how other groups react to them. Simulation games vary greatly in their complexity and length of time required to play them. Unfortunately, the closer the game resembles "reality", the more lengthy and complex it usually becomes. While simulation games can serve as an effective educational device -- as a method for informing the public of the consequences of various choices -- they typically do not provide opportunities for the public to provide comments specifically on study issues. As a result, simulation games could be used to educate an advisory group or leadership group of some sort, but must be used in conjunction with other public involvement techniques.

(a) Advantages of a Simulation Game: Simulation games can provide the public with information about the consequences of various policy positions or decisions. Simulation games can also provide the public with an understanding of the dynamics of an economic or environmental system. Participation in a simulation game is usually fun, and participants develop a rapport and communication which can be maintained throughout the entire study.

(b) Disadvantages of a Simulation Game: There are a number of simulation games on the market which are confusing, over-technical or misleading. Care must be exercised in selecting a simulation game appropriate for a particular study. No simulation games currently exist for aquifer restoration projects. While simulation games can be educational, they typically do not provide opportunities for direct public comment on a study. Since few games have a perfect fit with reality, citizens may apply the game rules inappropriately to the actual situation. People may become so engrossed in the game that they forget about the actual issues at hand.

Conflict management and resolution is becoming increasingly important in public participation programs. It could be important in the planning and implementation of an aquifer restoration project. As noted above, one technique for handling conflict is environmental mediation (Creighton, 1981b). In order to develop conflict management and resolution strategies it is necessary to understand the different type of conflicts, and the fact that behavior which may contribute to resolution of one kind, may exacerbate another. Creighton (1981a) delineated four types of conflicts:

(1) Cognitive Conflict: This is conflict which occurs when people have a different understanding or judgment as to the facts of a case. How extensive is the aquifer pollution? What are the costs for clean-up, etc.? When conflict is exclusively cognitive conflict, then it is possible to resolve the conflict if a process can be agreed upon to determine "the facts". Arguments over factors are often advanced, however, as part of values or interest conflict, so it is not always easy to distinguish the cognitive elements of a conflict from values or interest.

(2) Values Conflict: This is conflict over goals, whether or not a project (or outcome) is desirable/undesirable or should/should not occur. Obviously people with different values have a fundamentally different perspective from which they evaluate a proposed project. Values conflicts are also difficult to distinguish from cognitive or interest conflicts. People tend to accept those facts that support their values position; they also tend to adopt values consistent with their interest. This can quickly lead to a "chicken or the egg" argument -- do facts cause people to tend to certain values positions? Do they then take on roles (which define their interest) based on their values? Or does their self-interest dictate their values, which in turn filter the facts to which they pay attention? At a minimum, they are intertwined.

(3) Interest Conflict: Since the costs and benefits resulting from an aquifer restoration project are rarely distributed equally, some people will have a greater interest in a project than others. Some may have an interest in assuring it does not occur. As a result it is possible to have agreement on facts, and on values, and still have conflict based on interest. An aquifer restoration project that will lead to major industrial development may be ardently supported by downtown businessmen and opposed by suburban interests. They may agree on the effects of the project, they may even all agree that industrial development is a desirable goal, but since the businessmen may be heavily favored by the project there may still be conflict between the developers and the suburbanites.

(4) Relationship Conflict: There are several psychologically-oriented bases for conflict as well. Every time people communicate they communicate both content (information, facts) and relationship (how much someone is valued, accepted, etc.). Decision-making processes can also communicate relationship -- decision-making processes may, for example, favor those groups which are well enough financed and organized to present scientific supporting data over those who primarily argue from a values base. The result is that there are a number of emotional motivations that lead to conflict on grounds other than disagreement on facts or values, or interest differences. One group may feel insulted or oppressed by another. A group or individuals may feel that the decision-making process gives an advantage to one group or another. Individuals or groups may react to others based on emotional symbols such as hair-style, dress, or language. A group or individual may feel resentful that they were not consulted.

One approach for conflict management and resolution is to use environmental mediation via a third-party intervenor. Conflicts can arise in aquifer restoration projects over the significance of the pollution and the costs and cost allocations for clean-up. In some cases, the resolution of a conflict can be facilitated by a third party conciliator. In other cases, third party intervention may only serve to make the situation worse. The first decision, therefore, is whether third party intervention is appropriate in a particular dispute. Wehr (1979) identified five criteria which could be used in determining if third-party intervention would be helpful; the criteria are:

(1) Accessibility: Can a third party gain entry into the conflict? Do the conflicting parties view it as a "private dispute"?

(2) Tractability: Does the conflict offer some hope of successful resolution?

(3) Divisibility: Can the conflict be subdivided into smaller, more manageable segments? Can the third party intervene in only one segment?

(4) Timing: Is it too early or too late to intervene?

(5) Alternatives: Is intervention risky to successful resolution? Would non-intervention be a less risky course of action?

As noted earlier, not all conflicts are amenable to third-party intervention. Even with those that are, timing may be critical in the success or failure of the enterprise (Creighton, 1981a). As a result practical experience suggests that there are certain key conditions that must exist -- or must be within the power of the third party to create -- if the intervention is to be a success. These six key conditions are (Creighton, 1981a):

(1) Motivation towards resolution: The first requisite is that all critical parties must have motivations that make resolution desirable. If one major party can win more by no decision being made, the conditions for resolution do not

exist. If one party can only lose if a decision is reached, the conditions do not exist. The motivation towards resolution must also be assessed at a relationship or emotional level. If people are actively nursing grudges, insults, or slights (real or imagined), then the timing may be wrong. If people are beginning to think they are wasting emotional energy with all the psychological games, then the timing may be right. It should also be remembered that different sides have different degrees of viability. If a "loss" on this issue threatens the continued existence of a group, then it is forced to play by different rules than the organization that will continue to exist, no matter the outcome. This can be a major factor in creating motivation towards resolution, or against it.

(2) Roughly equal power: Neither side is likely to compromise if they think they have the political or legal power to "win" outright. This can apply where one side believes it has a clear-cut legal basis for its point of view, or it can apply where a group or individual is confident of winning through the courts or through intervention of outside political power. In effect, people will only negotiate when they can win more (or endanger less) by doing so. In some cases the role of the third party is to insist that both sides be treated as equals. This assumes that the third party has some power in the situation.

(3) The risks of failure not too great: The old saying is that "it is better to have tried and lost than never tried at all". That depends on the consequences of failure. Sometimes the consequences of a failure at third-party intervention may be that a controllable conflict may become totally dysfunctional. In other cases, when a visible effort at conciliation fails, this reinforces the negative perceptions on both sides. Even if the leadership is willing to continue negotiations they are often under intense pressure from their followers to take a hard-line position. Since the other side is almost invariably seen as the cause of the failed negotiations, the anger and resentment towards the adversaries is further increased.

(4) Organizational authority: To be effective, a conciliator must usually speak for an organization that possesses authority and credibility. Even when an individual is hired as a "mediator", he is placed in that position with the authority and credibility of the organization doing the hiring. If the organization the conciliator represents is not credible to the antagonists, the conciliator will not be accepted.

(5) Negotiability of issues: One of the tactics engaged in by a conciliator is to attempt to enlarge the number of issues which are negotiable. The more issues which are negotiable,

the more likelihood exists that a "positive-sum" solution can be found. This negotiability is a function of a number of things: a) the strength of the leadership of each group within their own organization, b) the consequences of a "loss" to the continued viability of a group or entity, c) the external pressures on the groups to compromise, and d) the skills of the conciliator.

(6) Control over the process: Experienced conciliators stress the importance of the conciliator's control over the communication process. This is particularly true in formal mediation, or at critical junctures in negotiations. Obviously the willingness of the antagonists to grant this kind of control is a function of the credibility and authority of the organization the conciliator represents, and the personal skills of the conciliator.

If it is decided that third party intervention is appropriate, the next step is selection of a conciliator (intervenor). There are two qualities which are essential in the intervenor: credibility and neutrality. The conflicting parties must believe that the intervenor is sincere in his job. He should be a person who has a good reputation, has successfully resolved disputes in the past, and has some authority. Secondly, he must have no vested interest in the dispute except the desire to see it settled. Baldwin (1978) identified some possible roles the intervenor can play in conflict management and resolution, including:

(1) Creating a climate of trust and a willingness to negotiate on the disputants' parts;

(2) Ensuring fair and adequate representation;

(3) Bringing the best available environmental information and expertise to the discussions;

(4) Breaking deadlocks by setting goals and deadlines;

(5) Suggesting solutions, or alternative solutions;

(6) Outlining implementation plans and helping create mechanisms for implementation and enforcement of the agreement.

Assuming that a third party intervenor is chosen, there are numerous things this individual can do to facilitate conflict resolution and management. Frost and Wilmot (1978) delineated the following seven suggestions for intervenors to facilitate their work:

(1) Be descriptive rather than judgmental. Describe behavior in terms of what your reaction is to it, rather than pinning a label on the other person.

(2) Encourage specificity. Feedback is more effective when it describes specific instances instead of general feelings.

(3) Deal with things that can be changed instead of "givens". Feedback is most effective when it concerns descriptions that are not inherent characteristics of persons or situations.

(4) Encourage parties to give feedback when it is requested. Or the intervention agent can ask parties to give feedback to each other when they need it, even if the need has not been articulated.

(5) Give feedback as close as possible to the behavior being discussed. Feedback sometimes serves as a kind of "instant replay" to a behavioral pattern that has been observed by the third party.

(6) Encourage feedback whose accuracy can be checked by others. In a group situation, sometimes people are unaware of their own word choices and behavior.

(7) Speak only for yourself. Encourage persons in conflicts to not speculate what other people think.

At some point during conflict resolution, the disputants must meet face-to-face to negotiate a mutually acceptable solution. This meeting must be carefully controlled, or it can degenerate into a shouting match. If negotiations are to be successful, all affected parties should be included. However, it is sometimes necessary to exclude all others. The presence of "observers" may retard progress because negotiators may assume extreme positions in the presence of witnesses. It is vital that the representatives of each party be persons with authority who can make commitments on behalf of their group. Creighton (1981a) has summarized the usual negotiating procedure into a four-step strategy. This strategy can be used whether the disputants are political factions, labor and management, countries, or project proponent and citizen. The four steps are as follows:

(1) Areas of Agreement: Parties enumerate all areas on which there is agreement. These are then eliminated from discussion. This step saves time later on and, most important, establishes common ground and fosters a feeling of mutual trust.

(2) Areas of Disagreement: Parties clearly define all areas of disagreement. Each party must state its position on each point of conflict, giving the underlying reasons for its position. This gives negotiators an idea of the magnitude of the problem. It also ranks points of conflict in a rough order of importance.

(3) Conflict Resolution Procedure: If possible, a procedure for resolving disagreements should be agreed upon. Doing this establishes a suitable climate in which agreements can be made.

(4) Negotiate Issue-by-Issue: It is not usually possible to resolve all outstanding disagreements at once. A more realistic approach is to try and solve points of conflict one at a time. It may be advisable to negotiate minor issues first and then progress to major ones. In this way, the negotiators will address the more difficult problems having a record of successful negotiations on less thorny issues.

An alternative approach for conflict management and resolution is to use the "Samoan Circle" (Aggens, 1981). The Samoan Circle meeting process is designed to facilitate the discussion of controversial issues when there is a large group of people interested in the topic. Its principal value is in the opportunity it affords for an exploration and exchange of knowledge and opinion where the large size of the group, or an environment of controversy, might disable other kinds of meetings. This meeting process is also useful when the possibility exists that no one person could be accepted as a fair moderator by all who might seek to be involved in the discussion.

In a Samoan Circle meeting, individuals can speak out on the issue without the need for oratorical skills, or the ability to put all their thoughts together into the one, short, cogent statement so often required by the dynamics of involvement in large group meetings. In this process, no one needs to be burdened with the responsibility of being the moderator of equitable participation, a judge of fairness, or the controller of other people's behavior. The advantages of small group discussion are afforded in the midst of a large group. The need and the opportunity for participants to use dramatics, "us/them" name-calling, and "cheerleading" in efforts to make their points are lessened.

The process does not resolve conflict. It is intended for the fullest possible exchange of information about an issue in anticipation of other group processes better designed for decision-making or conflict management. However, some users of the Samoan Circle have experienced the spontaneous resolution of conflicting views and agreement on actions required -- apparently as a result of the contestants in a controversy having heard one another for the first time. It is not recommended that users of this process anticipate this result.

The most notable characteristic of the Samoan Circle is that there is no one who is the Chairman, or Moderator, or Facilitator. It is a leaderless meeting. Responsibility for discipline in this kind of meeting is vested in everyone, rather than in meeting leaders. Everyone has, and will quickly see that he or she has, a clear stake and part in maintaining an orderly environment for discussion. Five key issues related to the use of the Samoan Circle are room arrangements, starting the meeting, meeting dynamics, meeting records and evaluation, and ending the meeting (Aggens, 1981).

(1) Room Arrangements: As many chairs as seem needed for the meeting should be set up in concentric circles, with the inner circle big enough in diameter to allow for a round table with five chairs. There should be enough space around the central table and five chairs for people to walk around it without having to climb over the legs of those sitting in the first circle of seats. Four or more aisles should be left open to permit people to move easily from seats in the concentric circles to seats at the center table. For large groups, a microphone should be placed on the center table to insure that discussion across this table can be heard easily by everyone in the room -- but it is destructive to the group dynamic intended if this microphone is handed around the table as each person takes a turn talking. People at the center table should be talking to one another, personally, at close range. They should not be coming to the center table only to gain access to the microphone in order to whip up enthusiasm among allies in the audience. An omni-directional microphone (taped down, if necessary) in the center of the table should be used -- but only when this is absolutely necessary because of the size of the group.

(2) Starting the Meeting: After the group has been called to order by the person who will begin and end the meeting, it should be stated that the purpose of the meeting is to learn from one another as much is possible about the topic that is at issue in the community -- including facts, problems, obstacles, needs, values, solution ingredients, suggestions for improvement, and new ideas. Representatives of the two or three sides that may be contesting over the issue could share in this introduction in an effort to strengthen the realization that the meeting process is not a contrivance or manipulation of one side by the other. The general rules for the meeting are, as stated by the organizing person:

(a) Anyone may participate by making a statement, asking a question, answering a question, taking exception to or confirming another person's opinion, making a rebuttal, and so on. But to do any of these things, the person who wants to say something must come to this center table and take a seat. Once there, he or she may interrupt, or wait for an opening in any discussion that is going on.

The person taking a seat can join in the discussion or try to change its direction, or raise a new topic.

(b) The discussion at any one time is limited to the five people who can be seated at this table. If you come to the table, you may stay as long as you feel you have a contribution to make to the discussion. You may leave and return again as often as you wish. If there are no vacant seats at the table and you want to get in on the discussion, stand near the table until someone gives up a seat. The more people there are standing near the table waiting for seats, the more this should signal those sitting in the discusison to evaluate their own need to continue to participate. If you want to talk to one of the people at the table, stand directly behind that person's chair as a signal to the others at the table that you want one of their seats.

(c) If you want to cheer, or groan, or make any other noises to represent your opinion, please come to the table, take a seat here, and then do it. Once I leave this table, I will be bound by these same rules. The discussion will go on until there is no one left at the table, or until the time for adjournment arrives.

(3) Meeting Dynamics: Once there are two or more people involved in the discussion, the talk takes on the "you-and-I" character of communication at short range. The oratory and belligerence that are common when "discussion" is taking place across the width of a 30-foot room lessens when people of different persuasions close the physical distance between them. Discussion across the round table is usually (but not always) more relaxed, temperate, conversant, and instructive. If people feel the need to assault one another over their convictions, oceans of space will not prevent this. When all the seats at the table are filled and a person comes to the center to wait for a vacancy to develop, it is not uncommon for everyone at the table to stand up and leave. The sense of self-discipline invoked by this unchaired meeting process is very strong in most groups. On the other hand, when no one comes to the center table to wait for a vacancy, those sitting at the table feel free to expand their discussion and register their opinions and feelings several times. Sponsors of this meeting process usually have to suppress the inclination to rush into such situations and shut off a talkative person, or suggest, in the name of equity, that others might want to be heard. If and when such actions are needed, plenty of time should be given for the group to make its own interruption of a monologue, or to show its need for more participant involvement by individual actions to accomplish this. Any

guidance needed from meeting sponsors should be given by someone who takes a seat at the table to express that need as a personal opinion.

(4) Meeting Records and Evaluations: A number of things can be added to the meeting process to make a record of transactions and to achieve some degree of "closure" that points at further action. Comments can be transcribed and the process used as a form of public hearing. (However, this meeting format seems inappropriate when formal, written statements are being read into the record.) Minutes can be kept. Decision-makers can be identified as auditors scattered throughout the audience. Comments can be written on newsprint on a wall. This can be done as a sequential list of opinions stated, or as a series of categorized lists -- such as: "advantages" and "disadvantages"; or "strengths of the proposal" and "suggestions for improvement in the proposal".

(5) Ending the Meeting: Discussion can be allowed to run its course if there is no time required for adjournment. The meeting room will gradually empty until there may be no more people left except for an intensely interested group at the center table. If time limits, or the need to move on to another agenda topic require the ending of the discussion before everyone has left the center table, a number of things can be done. Someone who is responsible for the time limits can take a seat at the table and call attention to the disappearing time and remind the group of the agreed-upon time for ending the meeting. This often causes a flurry of activity by people who have been holding back, but who are still intent upon getting their point of view heard. An announcement of the need to close the discussion should be made early enough to accommodate this last-minute rush. When the time to end the meeting is about five to ten minutes away, the person who started the meeting can move to the table, wait for a seat to be vacated if none is already empty, and withdraw that chair. Continuing to stand near the table, the "meeting-ender" can withdraw each chair as it is vacated. This action is frequently acknowledged by the audience with understanding chuckles and, sometimes, by a last-minute rush. The message: "I need to end this meeting", is clear and non-threatening; but the person ending the meeting should avoid cutting off last-minute participants from at least some chance at expression unless this is absolutely necessary and the need is obvious to all concerned. If any concluding comments are needed, these can be made when the person ending the meeting takes possession of the last chair.

The "Samoan Circle" has been used successfully by a variety of public agencies and private organizations (Aggens, 1981). Satisfaction with the meeting process seems to be related to a recognition by meeting sponsors and participants that it provided an environment for discussion of a controversial subject where other, more conventional, meeting processes had failed them in the past. In using this process, sponsors have modified it to fit peculiar circumstances, or make it "feel" better to the personalities involved.

PRACTICAL PLAN FOR IMPLEMENTING PUBLIC PARTICIPATION PROGRAM

Actual implementation of a public participation program involves a number of considerations. Delli Priscoli (1981) identified five major points to consider in creating an effective public involvement strategy:

(1) Implementation of citizen-involvement programs must start by realizing that initial dissonance will arise. The roots of that dissonance and its likely effects must be understood and anticipated. Initial conflicts, such as between public-affairs offices and public-involvement staff, should be usefully managed. Overall management rewards should be commensurate with the way the staff actually allocates time.

(2) Decisions must be made about how much sharing of decision should be done and can be done. The "should" versus "can" distinction of these decisions is critical. Often staff analysis of the "can" in sharing comes packaged to executives as the "should" of decision sharing.

(3) Public-involvement programs must be closely related to actual decision making. Either managers get into citizen-involvement programs or line-staff are given more decision authority. Agencies will find some point in between these extremes. At any rate, consultants should be used only as resources to consult. When outside consultants are given the responsibility for citizen involvement, decision makers become further isolated from the effects of their decisions. Consultants can provide critical staff support, training, evaluation, and critiques. But insofar as the success of citizen involvement depends on getting close to decisions, they should not replace decision makers.

(4) Training is one of the best long-range techniques in implementing public-involvement programs. Training should be coupled to strategies of recruiting new personnel. It must

also be keyed to varying audiences within the agency. Effective training programs require enough flexibility to change as the agency and issues change in the process. Interactive training models offer even further public-involvement opportunities. Joint training prorams themselves can become public-involvement techniques.

(5) Public-involvement techniques must be appropriate -- in time and money -- to the type of decision being made. As such, funding can become a major consideration in the successful citizen-involvement program. Public involvement techniques must be clearly linked to the decision making process. There is, of course, budgeting for line decision-making activities, such as interviews, advertising, press releases, hearings, large and small meetings, workshops, surveys, and reports; but something called citizen involvement funding is difficult to conceptualize. It is more difficult to trace professional staff time in design, concern, and interaction for citizen involvement, because these attitudinal orientations should become part of the larger professional job definition. Table E.7 provides general approximations of the costs of various techniques (Delli Priscoli, 1981).

Practical Suggestions for Implementing Program

The following list of items represents some very practical ideas and suggestions that can be useful in organizing a public participation program (Canter, 1977):

(1) Coordinate the various Federal, state, and local agencies that have interests and responsibilities in the same geographic or technical areas of the study. Develop formal agreements or informal relationships.

(2) Develop lists of groups and citizens in the geographic area who have previously expressed interests or potential interests in the study.

(3) Assemble a newspaper clipping file on project needs and previous history of the project or study.

(4) Try to convey the attitude -- "What can we do in this study to assist you in your local planning problems? How can we coordinate with other local ground water efforts and projects?" This is in contrast to the attitude -- "We are here to solve your problems and prepare plans and studies for you."

Table E.7: Rough Cost Guide to Most Frequently Used Public Involvement Techniques (Delli Priscoli, 1981)

Technique	1978 Cost ($)
Interviews (per 20-min interview)	15-30
Newspaper advertising	250-750
Radio advertising	250-750
Press release	100-500
Public hearing	2,500-6,500*
Large public meeting	2,500-6,500*
Small meeting or workshop	2,000-4,000*
Publicity on radio or TV	250-500
50-page report	5,000-10,000
200-page report	10,000-50,000
Information bulletins (4-8 pages)	500-1,500
Conducting a survey:	
Per mailed questionnaire	3-5
Per telephone interview	10-15
Per personal interview	15-30

*May be reduced if a series of identical workshops or meetings is held.

(5) Disseminate study information through the news media (newspaper, radio, and television) and through regular publication of a planning newsletter. The mailing list should encompass all state and Federal interests as well as local groups and individuals who have participated in previous meetings or shown interest in the study.

(6) Every third or fourth issue of the newsletter should contain a mail-in coupon for persons wanting to continue to receive the newsletter. Each issue should contain a coupon for suggestions of other persons or groups that should receive the newsletter.

Some practical suggestions for actually conducting a public meeting are as follows (Canter, 1977):

(1) Keep data presentations simple. The purpose of data presentations is to inform, and not to confuse or disillusion.

(2) An outline of any project or alternative should include a discussion of location, features, benefits and costs, and beneficial and detrimental environmental impacts.

(3) Use simple visual aids. Slides of the actual area prove very beneficial.

(4) Discuss project timing (prior authorizations and resolutions) previous to the meeting and the anticipated timing of future required steps.

(5) Discuss general concept, features and requirements of benefit-cost ratio, or other relevant economic analysis.

(6) Only those persons who can speak on general matters, comingled with engineering expertise, should be considered for meeting with the public. It is well known that not everybody has the ability to speak, answer questions, and perhaps debate while holding a specific image in front of the public. The ability to speak well is not the only trait on which the selection should be based. A person who can answer questions quickly and confidently from an audience in which the sentiment is mixed or opposed can establish a profound positive relation with the audience.

(7) Avoid use of technical jargon or words that may be hard to understand, especially with local groups unaccustomed to engineering and hydrogeological terminology.

(8) Be familiar with the area.

(9) Be earnest, sincere, and willing to work on problems with individual groups.

Incorporation of Results in Decision-Making

The feedback loop from public participation must be used in the decision making process, or the purpose of public participation will not have been fully satisfied (Canter, 1977). Public participation results can be useful in defining project need, describing unique features of the environmental setting, and identifying environmental impacts of potential alternatives. Results can also be utilized by the proposing agency in assigning significance (importance) values to both environmental items and values. Finally, selection of the most desirable alternative for meeting the identified aquifer restoration need can be aided by public participation.

Two levels are suggested for incorporation of public participation information in the decision making process. First, all public meetings and the entirety of the planned and accomplished public participation program should be summarized. Any information relative to the objectives outlined earlier and obtained through questionnaire surveys or other public participation techniques should be summarized. Second, public preference can be used in selection of the alternative to become the proposed project for meeting the aquifer restoration need.

SELECTED REFERENCES

Aggens, L., "The Samoan Circle: A Small Group Process for Discussing Controversial Subjects", in "Public Involvement Techniques: A Reader of Ten Years Experience at the Institute of Water Resources", Creighton, J.L., and Delli Priscoli, J., editors, IWR Staff Report 81-1, 1981, U.S. Army Engineer Institute for Water Resources, Fort Belvoir, Virginia.

Arnstein, S.R., "A Ladder of Citizen Participation", Journal of the American Institute of Planners, Vol. 35, No. 4, July 1969.

Baldwin, P., "Environmental Mediation: An Effective Alternative?", Proceedings of Conference Held in Reston, Virginia, Jan. 11-13, 1978, RESOLVE, Center for Environmental Conflict Resolution, Palo Alto, California.

Bishop, A.B., "Structuring Communications Programs for Public Participation in Water Resources Planning", IWR Contract Report 75-2, May 1975, Institute for Water Resources, Fort Belvoir, Virginia.

Bishop, A.B., "Communication in the Planning Process", in "Public Involvement Techniques: A Reader of Ten Years Experience at the Institute of Water Resources", Creighton, J.L., and Delli Priscoli, J., editors, IWR Staff Report 81-1, 1981, U.S. Army Engineer Institute for Water Resources, Fort Belvoir, Virginia.

Canter, L.W., Miller, G.D. and Fairchild, D.M., "Sentry Missile Environmental Assessment Program", Report submitted to U.S. Army Ballistic Missile Division Systems Command, Huntsville, Alabama, Sept. 1982, 2424 pages.

Canter, L.W., Environmental Impact Assessment, 1977, McGraw Hill Book Company, Inc., New York, New York, pp. 220-232.

Council on Environmental Quality, "National Environmental Policy Act -- Regulations", Federal Register, Vol. 43, No. 230, Nov. 29, 1978, pp. 55978-56007.

Creighton, J.L., Chalmers, J.A. and Branch, K., "Integrating Planning and Assessment Through Public Involvement", in "Public Involvement Techniques: A Reader of Ten Years Experience at the Institute of Water Resources", Creighton, J.L., and Delli Priscoli, J., editors, IWR Staff Report 81-1, 1981, U.S. Army Engineer Institute for Water Resources, Fort Belvoir, Virginia.

Creighton, J.L., and Delli Priscoli, J., "Establishing Citizens' Committees", in "Public Involvement Techniques: A Reader of Ten Years Experience at the Institute of Water Resources", Creighton, J.L., and Delli Priscoli, J., editors, IWR Staff Report 81-1, 1981, U.S.Army Engineer Institute for Water Resources, Fort Belvoir, Virginia.

Creighton, J.L., "Acting as a Conflict Conciliator", in "Public Involvement Techniques: A Reader of Ten Years Experience at the Institute of Water Resources", Creighton, J.L., and Delli Priscoli, J., editors, IWR Staff Report 81-1, 1981a, U.S. Army Engineer Institute for Water Resources, Fort Belvoir, Virgina.

Creighton, J.L., "A Short Catalogue of Public Involvement Techniques", in "Public Involvement Techniques: A Reader of Ten Years Experience at the Institute of Water Resources", Creighton, J.L., and Delli Priscoli, J., editors, IWR Staff Report 81-1, 1981b, U.S. Army Engineer Institute for Water Resources, Fort Belvoir, Virginia.

Creighton, J.L., "Identifying Publics/Staff Identification Techniques", in "Public Involvement Techniques: A Reader of Ten Years Experience at the Institute of Water Resources", Creighton, J.L., and Delli Priscoli, J., editors, IWR Staff Report 81-1, 1981c, U.S. Army Engineer Institute for Water Resources, Fort Belvoir, Virginia.

Delli Priscoli, J., "Implementing Public Involvement Programs in Federal Agencies", in "Public Involvement Techniques: A Reader of Ten Years Experience at the Institute of Water Resources", Creighton, J.L., and Delli Priscoli, J., editors, IWR Staff Report 81-1, 1981, U.S. Army Engineer Institute for Water Resources, Fort Belvoir, Virginia.

Frost, J.H. and Wilmot, W.W., Interpersonal Conflict, 1978, Wm. C. Brown Company Publishers, Dubuque, Iowa.

Hanchey, J.R., "Objectives of Public Participation", in "Public Involvement Techniques: A Reader of Ten Years Experience at the Institute of Water Resources", Creighton, J.L., and Delli Priscoli, J., editors, IWR Staff Report 81-1, 1981, U.S. Army Engineer Institute for Water Resources, Fort Belvoir, Virginia.

Ragan, Jr., J.F., "An Evaluation of Public Participation in Corps of Engineers Field Offices", in "Public Involvement Techniques: A Reader of Ten Years Experience at the Institute of Water Resources", Creighton, J.L., and Delli Priscoli, J., editors, IWR Staff Report 81-1, 1981a, U.S. Army Engineer Institute for Water Resources, Fort Belvoir, Virginia.

Ragan, Jr., J.F. "Constraints on Effective Public Participation", in "Public Involvement Techniques: A Reader of Ten Years Experience at the Institute of Water Resources", Creighton, J.L., and Delli Priscoli, J., editors, IWR Staff Report 81-1, 1981b, U.S. Army Engineer Institute for Water Resources, Fort Belvoir, Virginia.

Schwertz, Jr., E.L., "The Local Growth Management Guidebook", 1979, Center for Local Government Technology, Oklahoma State University, Stillwater, Oklahoma.

U.S. Army Corps of Engineers, "Public Participation in Water Resources Planning", EC 1165-2-100, May 1971, Washington,D.C.

U.S. Department of Transportation, "Effective Citizen Participation in Transportation Planning: Community Involvement Processes", 2 volumes, 1976, Washington, D.C.

Wehr, P., Conflict Regulation, 1979, Westview Press, Boulder, Colorado.

APPENDIX F

RISK ASSESSMENT AS RELATED TO AQUIFER RESTORATION PLANNING

INTRODUCTION

Risk assessment is a frequently used term in the 1980's, with its meaning encompassing a wide range of concerns. In the early 1970's a popular term was "environmentalist", with its meaning encompassing a wide spectrum of disciplines and perspectives related to environmental management. In like manner, risk assessment also includes a wide spectrum of disciplines and perspectives. Disciplines engaged in risk assessment include, but are not limited to, engineers, hydrogeologists, environmental scientists, chemists, microbiologists, geologists, geographers, and public administrators. Perspectives on risk assessment range from concerns about ground water pollution to human health to financial decision-making. Approaches for doing a risk assessment may range from considering selected chemical properties of materials to calculation of numerical indices to presentation of information on the probabilities and likely consequences of catastrophic events. Therefore, the growing field of risk assessment is very broad. The purpose of this appendix is to summarize some information related to this field, particularly as focused on ground water pollution concerns. Background information on, and elements of, risk assessment will be presented along with a discussion of environmental risk analysis and risk assessment as related to examples of hazardous waste disposal sites.

BACKGROUND INFORMATION

Terminology associated with risk assessment is illustrated by the following definitions:

Risk: (1) function of the probability of an event occurring and the magnitude or severity of the event should it occur (Berger, 1982); (2) measure of the probability and severity of adverse effects (Conway, 1982); (3) possibility of harm, loss, or injury (Lee and Nair, 1979); and (4) collective chance or probability of accidents and disease resulting in injury or death (Inhaber, 1982).

Risk Assessment: (1) the identification of hazards, the allocation of cause, the estimation of probability that harm will result, and the balancing of harm with benefit (Berger, 1982); process of determining the probability that certain activities will produce certain adverse effects (Cornaby, et al., 1982); process including both risk analysis and safety analysis, where risk analysis is a quantitative assessment of the consequences of decisions, and safety analysis is the assessment of the level of risk acceptable to society (Jutro and Nerode, 1981).

Environmental Risk Analysis: process of predicting where in the environment a chemical will be transported, the rate and extent of its transformation, and its effect on organisms and environmental processes at expected ambient levels (Conway, 1982).

Environmental Risk Assessment: evaluation of both scientific data and the social, economic, and political factors that must be considered in reaching an ultimate decision on the prohibition, control, or management of chemicals in the environment; the final decision making involves the scientific measurement of risk and then a social judgment of whether the benefits of the product outweigh the risk (Conway, 1982).

Risk assessments are being used to satisfy a wide range of purposes. The chief purpose of risk assessment should be to aid decision making, and this focus should be maintained throughout any risk assessment (Lee and Nair, 1979). Risk assessments may be used to determine whether a particular substance is safe enough to be used, or whether a particular site is suitable for waste disposal. Relative to hazardous waste sites, risk assessments are intended to clarify the degree of hazard and thereby help determine: (1) the priority for conducting detailed environmental evaluations and for undertaking preventive or remedial action or (2) the extent and character of the preventive or remedial action (Schweitzer, 1981). The decision as to whether or not to clean up an uncontrolled hazardous waste site that is leaking involves weighing the costs of cleanup against the risks resulting from continued leakage (Nisbet, 1982).

New information and various societal actions have increased the need for conduction of risk assessments. Conway (1982) cited the following as increasing the needs for environmental risk analyses:

(1) Discovery that certain chemicals persist in the environment and could have adverse effects at higher levels, e.g., polychlorinated biphenyls (PCBs), dioxins, and fluorocarbons.

(2) Rapid growth of the chemical industry and the many other human activities (e.g., fuel production and use) that introduce chemicals into the environment.

(3) The Federal Toxic Substances Control Act (TSCA), which requires information on ecological fate and effects for new products, significant-new-use products, priority commercial materials, and chemicals suspected of having substantial risks.

(4) The Federal Resource Conservation and Recovery Act (RCRA), which requires information regarding the fate and effects of leachates from land disposal of hazardous solid wastes.

(5) The Federal Clean Water Act Amendments, which require that receiving water quality criteria be developed for toxic pollutants.

(6) Studies of hazardous air pollutants under the Federal Clean Air Act.

(7) The need for managers of manufacturing and distribution operations to know the environmental impact of materials they handle so that they are able to make decisions, especially in emergencies.

(8) Customers' demand for environmental fate-and-effects information from their suppliers.

(9) The need for product development to be guided by a combination of information on efficacy, economics, health effects, and environmental effects.

Required information for risk assessment must be assembled from a variety of sources (Schweitzer, 1981). For example, clinical and epidemiological studies to investigate human health effects as the pivotal concern in risk assessments have been triggered by reports of worker exposures in certain manufacturing facilities. Modeling techniques, using limited data on chemical properties, have been employed to predict future risks that might result from the manufacture and use of newly developed chemicals. Materials balance studies have been important in estimating environmental discharges from certain production processes and certain uses as a basis for risk assessments of industrial chemicals such as vinyl chloride and formaldehyde. While monitoring data have often been used in such assessments, only on a few occasions were the monitoring data collected in a systematic manner designed to support authoritative risk assessments. The most widely used methodologies for assessing chemical risks have emphasized a chemical-by-chemical analysis. One approach has been to estimate the toxicity of the chemical as a function of dose, usually drawing on the results of laboratory experiments. A second approach relies on direct observations of the biological effects of the chemical exposure, effects either on human populations or more frequently on biological surrogate populations. In either approach the dose levels or the effects to critical receptor populations are estimated, with the risk then determined to be the probability that a person within the exposed population of concern will suffer an adverse effect from the likely exposure. The uncertainties in these methodologies as illustrated in Figure F.1 are well known. They include the problems of extrapolating

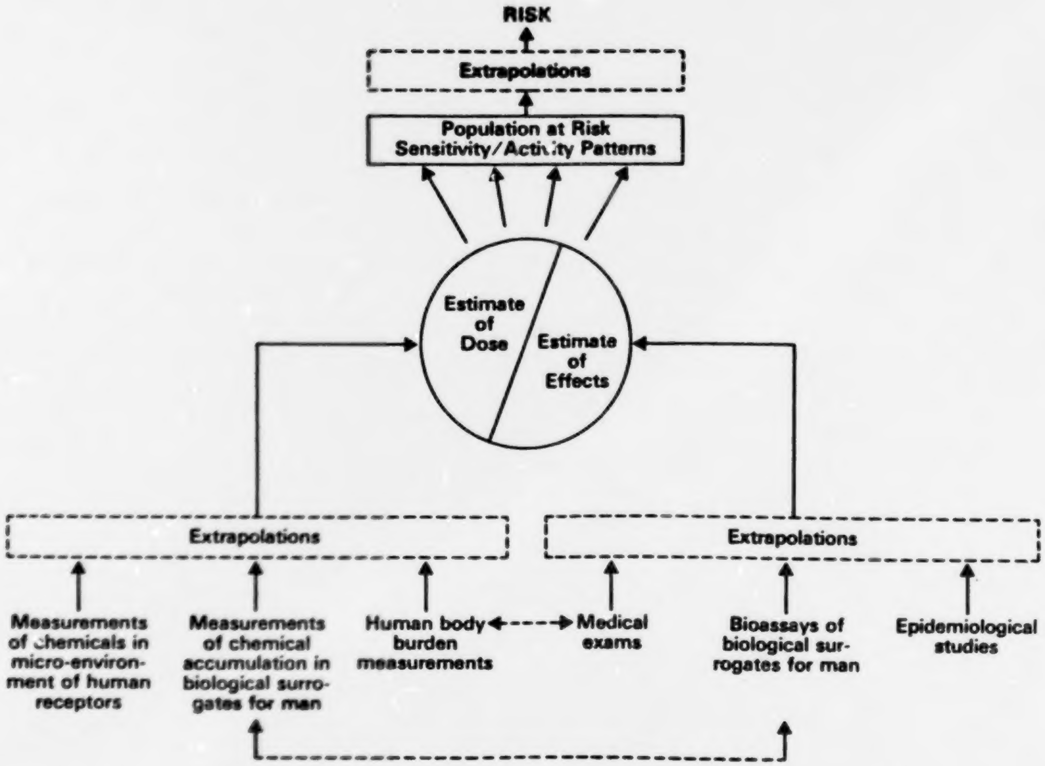

RISK
Extrapolations
Population at Risk
Sensitivity/Activity Patterns
Estimate of Dose
Estimate of Effects
Extrapolations
Extrapolations
Measurements of chemicals in micro-environment of human receptors
Measurements of chemical accumulation in biological surrogates for man
Human body burden measurements
Medical exams
Bioassays of biological surrogates for man
Epidemiological studies

Figure F.1: Extrapolations Required in Determining Risk (Schweitzer, 1981).

effects from laboratory animals to man, in determining the critical receptor populations and their activity patterns, and in estimating dose levels.

Additional uncertainties or limits related to risk assessments have been delineated by Ess and Shih (1982), and by Nisbet (1982). Ess and Shih (1982) presented uncertainties or limits in terms of the characteristics of risk. They noted that risk can be modeled as a chain or series of events as shown in Figure F.2. As indicated in Figure F.2, the events that occur in this path are termed hazard, outcome, exposure, and consequence. Interconnected hazards, outcomes, etc. exist in the real world, thus risk assessment must address complicated and overlapping risk paths. The second characteristic of risk is that many of the events of concern are relatively rare occurrences. This means that a good base of historical statistical data on event occurrence frequencies is limited or nonexistent. This problem is further complicated by the final characteristic which needs to be considered. Many of the elements of risk pathways, such as the specific toxic substance involved, are new and therefore unknown.

Special difficulties are associated with risk assessments for toxic chemicals and hazardous waste sites. Nisbet (1982) indicated that risk assessments for toxic chemicals are difficult because exposure is usually variable and poorly characterized, and because toxicity information is difficult to extrapolate from animals to humans. The problems are much greater for hazardous waste sites, for several reasons. First, the wastes are often poorly characterized chemically, especially when they result from disposal in the "bad old days" of the

Event	Hazard →	Outcome →	Exposure →	Consequence
Example	Tree struck by lightning	Tree falls	Man walking in woods	Injury to man

Figure F.2: Pathway Concept (Ess and Shih, 1982).

past. Even when the chemicals present in the wastes are reasonably well known, they are usually present as complex and variable mixtures, which makes it very difficult to assess either exposure or toxicity. In uncontrolled landfills, for example, where wastes are leaking into subsoil and ground water, the variability of underground media makes it very difficult to calculate rates of dispersion, and the variability of underground concentrations makes it difficult to measure rates of dispersion without elaborate and expensive monitoring programs. The toxicity of mixtures is very rarely measured, and is difficult to assess theoretically because so little is known about interactions and synergisms. Finally, without knowledge of the rate of dispersion, even the size of the population at risk is difficult to estimate reliably.

ELEMENTS OF RISK ASSESSMENT

Lee and Nair (1979) identified two basic elements associated with risk assessment: (1) risk quantification or estimation; and (2) risk evaluation. Risk quantification includes defining the hazard, identifying the initiating event(s) which would cause the hazard, determining the response and consequences to the receptor system, and assigning probabilities of occurrence. One tool which provides a structure for risk quantification is the event tree. Event trees such as the one in Figure F.3 provide a structured approach for risk quantification. For example, assume that the initiating event in Figure F.3 is the placement of hazardous materials at a site with two liners. System 1 represents the primary (top) liner and System 2 the secondary (bottom) liner. If System 1 fails and System 2 works, there is no

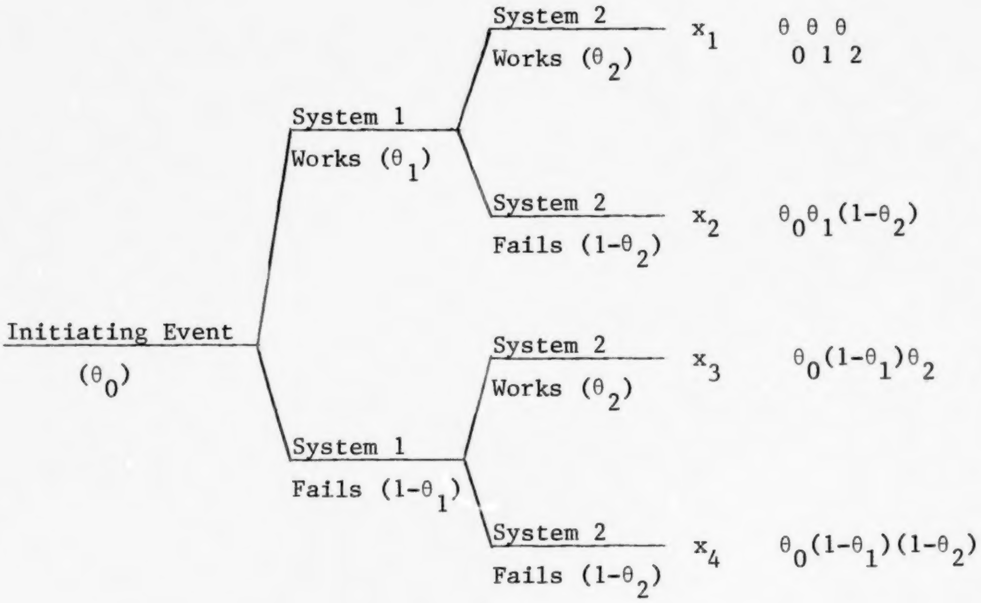

Initiating Event
(θ_0)
System 1
Works (θ_1)
System 1
Fails ($1-\theta_1$)
System 2
Works (θ_2)
System 2
Fails ($1-\theta_2$)
System 2
Works (θ_2)
System 2
Fails ($1-\theta_2$)
x_1
$\theta_0 \theta_1 \theta_2$
x_2
$\theta_0 \theta_1 (1-\theta_2)$
x_3
$\theta_0 (1-\theta_1) \theta_2$
x_4
$\theta_0 (1-\theta_1)(1-\theta_2)$

Figure F.3: Risk Quantification Using an Event Tree (Lee and Nair, 1979)

damage except expenses to repair System 1. However, if both systems fail there is the possible release of the hazardous materials to the sub-surface environment. Figure F.3 shows how the probabilities of each branch of the event tree can be calculated. While not related to aquifer restoration, Figure F.4 is an example of an event tree used in a risk assessment of liquified natural gas (LNG) spills in a coastal harbor (Lee and Nair, 1979). Decision trees can also be developed as a part of the risk quantification process. Figure F.5 displays a generalized decision tree structure for problems which largely involve risk (Shih and Ess, 1982). Attribute magnitude refers to the probability of occurrence for a given consequence.

Risk evaluation involves determining what risks are socially acceptable. One approach for risk evaluation is to compare the quantified risk with various existing risks encountered in everyday life (Lee and Nair, 1979). Table F.1 summarizes some of these daily risks (Conway, 1982). This evaluation approach is known as the "revealed societal preferences" approach. Risk evaluation is the most difficult and potentially controversial part of risk assessment.

ENVIRONMENTAL RISK ANALYSIS

Moving from general risk assessment to consideration of environmental risk analysis, Conway (1982) suggested the following four major approaches:

(1) The "stochastic-statistical" approach, in which large amounts of data are obtained under a variety of conditions, and the correlations are established between the input of a certain material and its observed concentrations and its effects in various environmental compartments.

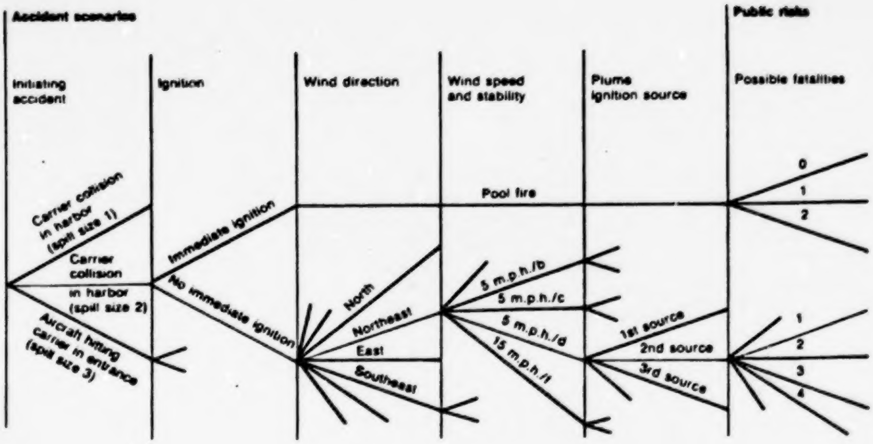

Accident scenarios
Public risks
Initiating accident
Ignition
Wind direction
Wind speed and stability
Plume ignition source
Possible fatalities
Carrier collision in harbor (spill size 1)
Carrier collision in harbor (spill size 2)
Aircraft hitting carrier in entrance (spill size 3)
Immediate ignition
No immediate ignition
Pool fire
0
1
2
North
Northeast
East
Southeast
5 m.p.h./b
5 m.p.h./c
5 m.p.h./d
15 m.p.h./f
1st source
2nd source
3rd source
1
2
3
4

Figure F.4: An Event Tree Analysis of LNG Spills (Lee and Nair, 1979)

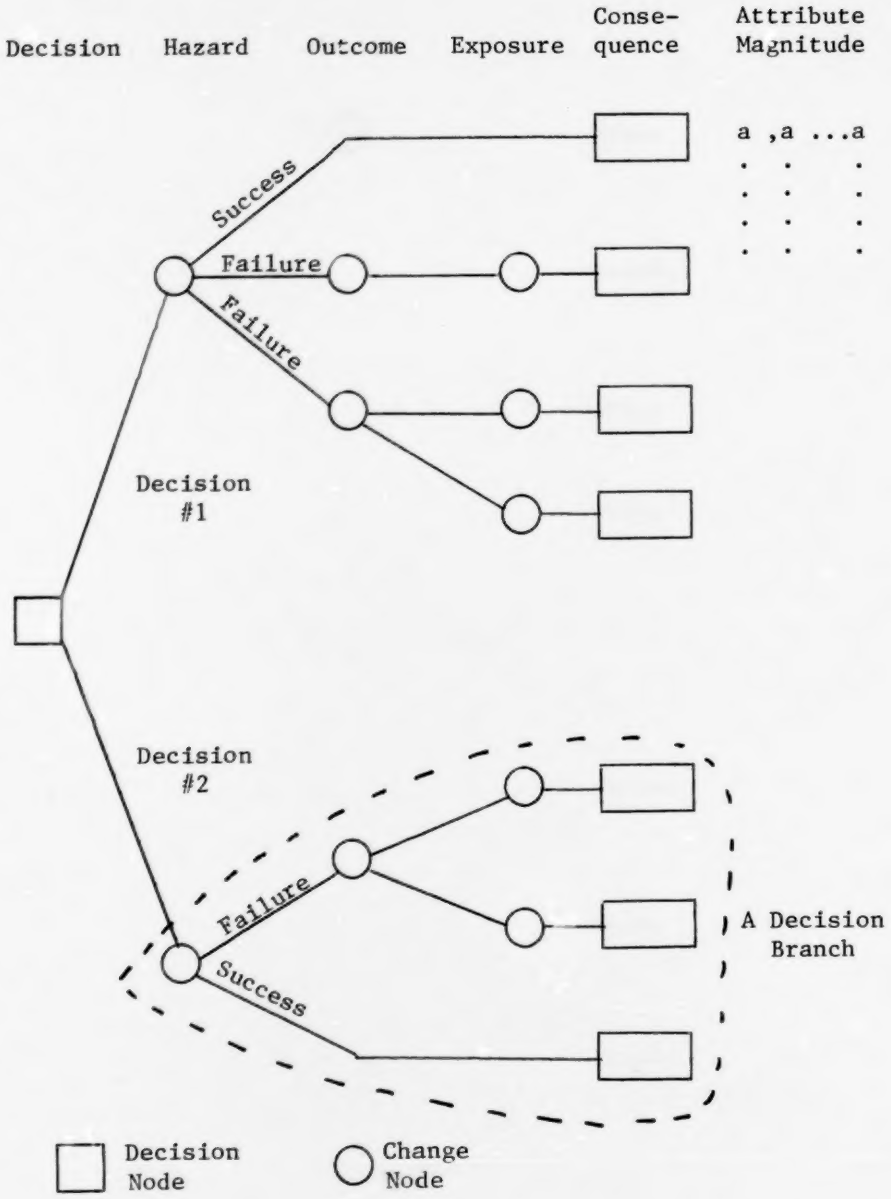

Decision
Hazard
Outcome
Exposure
Conse-quence
Attribute Magnitude
a ,a ...a
Success
Failure
Failure
Decision #1
Decision #2
Failure
Success
A Decision Branch
Decision Node
Change Node

Figure F.5: Generalized Decision Tree Structure (Shih and Ess, 1982).

Table F.1: Actions Increasing Risk of Death by One in a Million (Conway, 1982).

Action	Nature of Risk
Smoking 1.4 cigarettes	Cancer, heart disease
Drinking 0.5 liter of wine	Cirrhosis of the liver
Spending 1 hour in a coal mine	Black lung disease
Spending 3 hours in a coal mine	Accident
Living 2 days in New York or Boston	Air pollution/heart disease
Traveling 6 minutes by canoe	Accident
Traveling 10 miles by bicycle	Accident
Traveling 30 miles by car	Accident
Flying 1000 miles by jet	Accident
Flying 6000 miles by jet	Cancer caused by cosmic radiation
Living 2 months in Denver on vacation from New York	Cancer caused by cosmic radiation
Living 2 months in average stone or brick building	Cancer caused by natural radioactivity
One chest x-ray taken in a good hospital	Cancer caused by radiation
Living 2 months with a cigarette smoker	Cancer, heart disease
Eating 40 tablespoons of improperly stored peanut butter	Liver cancer caused by aflatoxin B
Drinking heavily chlorinated water (e.g., Miami) for 1 year	Cancer caused by chloroform
Drinking 30 12-oz. cans of diet soda	Cancer caused by saccharin
Living 5 years at site boundary of a typical nuclear power plant in the open	Cancer caused by radiation
Drinking 1000 24-oz. soft drinks from recently banned plastic bottles	Cancer from acrylonitrile monomer
Living 20 years near PVC plant	Cancer caused by vinyl chloride (1976 standard)
Living 150 years within 20 miles of a nuclear power plant	Cancer caused by radiation
Eating 100 charcoal broiled steaks	Cancer from benzopyrene
Risk of accident by living with 5 miles of a nuclear reactor for 50 yr	Cancer caused by radiation

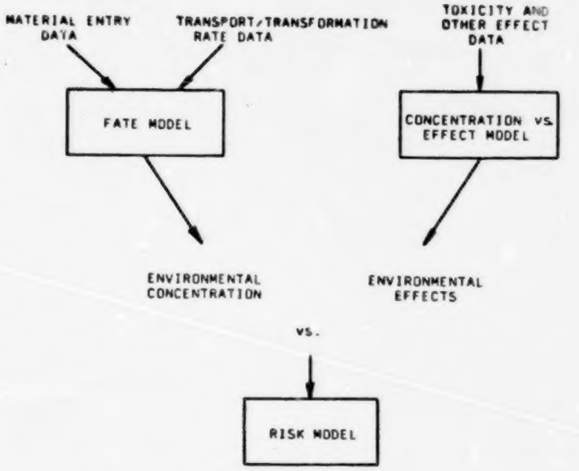
(2) The model ecosystem ("microcosm") approach, in which a physical model of a given environmental situation is constructed, dosed with a chemical, and the fate and effects of the chemical are observed.

(3) The "deterministic" approach, which uses a simple mathematical model to describe the rates of individual transformations and transports of the chemical in the environment. Only the dominant mechanisms, grouped as much as possible, are studied to arrive at an estimate of Expected Environmental Concentration (EEC). Separate determinations of toxicity with indicator organisms are made. This is the approach proposed in the TSCA premanufacture-notice testing guidelines. Figure F.6 depicts this approach.

(4) The "baseline chemical" approach, in which transformations, transports, and effects are measured as in the deterministic approach, but the results then are compared with data on chemicals of known degrees of risk.

Cornaby, et al. (1982) suggested a deterministic approach for hazardous waste sites when they identified the three elements shown in Figure F.7. The environmental fate and potential receptors near a waste site are depicted in Figure F.8 (Schweitzer, 1981). The approach suggested by Cornaby, et al. (1982) integrates human and nonhuman or ecological aspects of environmental concerns as shown in Figure F.9.

One of the key aspects of environmental risk analysis is associated with determining the transport and fate of chemicals in surface and ground water, air, and soil. Table F.2 provides a listing of mechanisms affecting the environmental fate of chemicals (Conway, 1982). It is beyond the scope of this presentation to discuss in detail various environmental transport and fate mathematical models. Another key aspect of environmental risk analysis is related to determining the ecological effects of chemicals to be released. Laboratory testing for both chemical fate and ecological effects may be necessary, and Table F.3 lists some candidate tests (Conway, 1982).


MATERIAL ENTRY DATA
TRANSPORT/TRANSFORMATION RATE DATA
TOXICITY AND OTHER EFFECT DATA
FATE MODEL
CONCENTRATION VS. EFFECT MODEL
ENVIRONMENTAL CONCENTRATION
ENVIRONMENTAL EFFECTS
VS.
RISK MODEL

NOTE: MODELS CAN BE SIMPLE MATHEMATICAL EXPRESSIONS OR YES-NO COMPARISONS WITH PRE-ESTABLISHED LEVELS AND RATIOS THAT TRIGGER CERTAIN ACTIONS.

Figure F.6: Deterministic Approach to Environmental Risk Analysis (Conway, 1982).

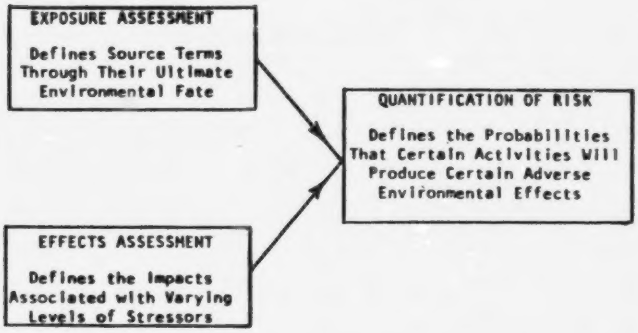

EXPOSURE ASSESSMENT
Defines Source Terms Through Their Ultimate Environmental Fate
EFFECTS ASSESSMENT
Defines the Impacts Associated with Varying Levels of Stressors
QUANTIFICATION OF RISK
Defines the Probabilities That Certain Activities Will Produce Certain Adverse Environmental Effects

Figure F.7: Overview of the Three Basic Elements of Environmental Risk Assessment (Cornaby, et al., 1982).

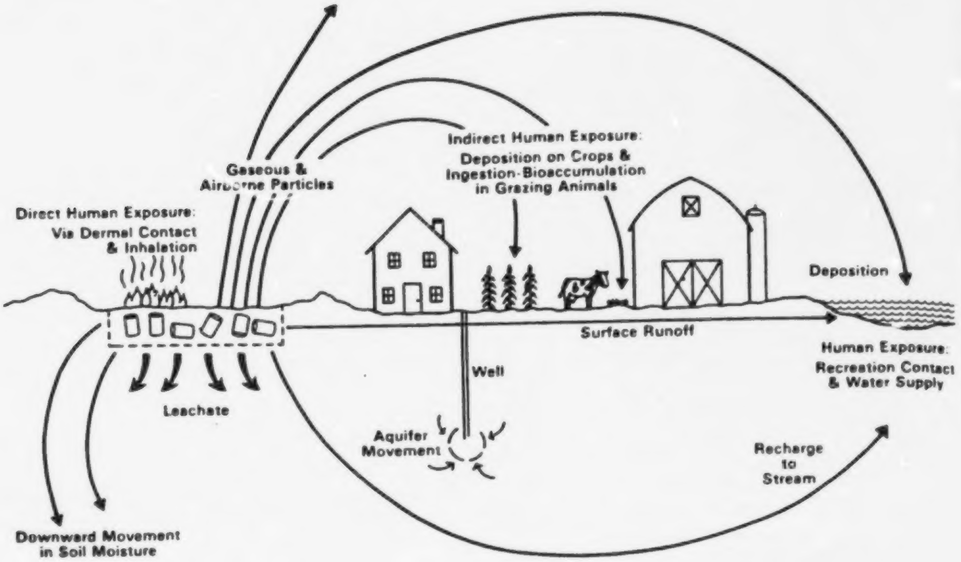

Gaseous &
Airborne Particles
Indirect Human Exposure:
Deposition on Crops &
Ingestion-Bioaccumulation
in Grazing Animals
Direct Human Exposure:
Via Dermal Contact
& Inhalation
Deposition
Surface Runoff
Human Exposure:
Recreation Contact
& Water Supply
Well
Leachate
Aquifer
Movement
Recharge
to
Stream
Downward Movement
in Soil Moisture

Figure F.8: Environmental Pathways from a Waste Site (Schweitzer, 1981)

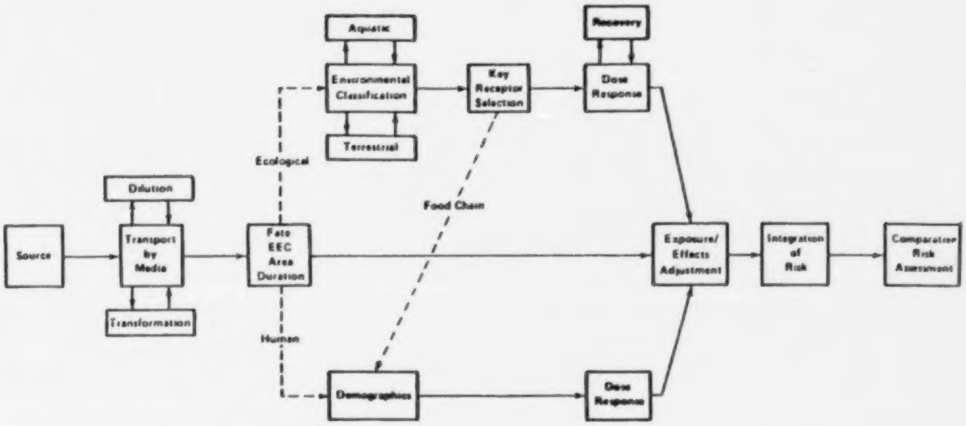

Aquatic
Recovery
Environmental Classification
Key Receptor Selection
Dose Response
Terrestrial
Ecological
Dilution
Food Chain
Source
Transport by Media
Fate EEC Area Duration
Exposure/ Effects Adjustment
Integration of Risk
Comparative Risk Assessment
Transformation
Human
Demographics
Dose Response

Figure F.9: Overall Environmental Risk Assessment Scheme (Cornaby, et al., 1982)

Table F.2: Methanisms Affecting Environmental Fate of Chemicals (Conway, 1982).

- **I. Original Input to Environment During Manufacturing, Distribution, Use, and Disposal**
  - A. To Water
    - 1. Treatment plant effluents at manufacturing and/or formulating plants
    - 2. Spills during manufacturing (original and formulating) and distribution
    - 3. Disposal after use
  - B. To Soil
    - 1. Direct applications as an agricultural chemical or for vegetation control
    - 2. Land disposal, e.g., landfill or land cultivation operations
    - 3. Spills
  - C. To Atmosphere
    - 1. Stack emission during manufacture
    - 2. Fugitive volatilization losses, e.g., from leaks, storage tank vents, and wastewater treatment
    - 3. Losses during use and subsequent disposal
- **II. Mechanisms for Transformation and Transport Within and Between Environmental Compartments**
  - A. Water
    - 1. Transport from water to atmosphere, sediments, or organisms
      - a. Volatilization
      - b. Adsorption onto sediments; desorbtion
      - c. Absorption into cells (protista, plants, animals); desorption
    - 2. Transformations
      - a. Biodegradation (effected by living organisms)
      - b. Photochemical degradation (nonmetabolic degradation requiring light energy), direct or via a sensitizer
      - c. Chemical degradation (effected by chemical agents), e.g., hydrolysis, free-radical oxidation
  - B. Soil
    - 1. Transport to water, sediments, atmosphere, or cells
      - a. Dissolution in rain water
      - b. Adsorbed on particles carried by runoff
      - c. Volatilized from leaf or soil surfaces
      - d. Taken up by protista, plants, and animals
    - 2. Transformation
      - a. Biodegradation
      - b. Photodegradation on plant and soil surfaces
  - C. Atmosphere
    - 1. Transport from atmosphere to land or water
      - a. Adsorption to particulate matter followed by gravitational settling or rain washout
      - b. Washout by being dissolved in rain
      - c. Dry deposition (direct absorption in water bodies)
    - 2. Transport within atmosphere
      - a. Turbulent mixing and diffusion within troposphere
      - b. Diffusion to stratosphere
    - 3. Atmospheric transformations
      - a. Photochemical degradation by direct absorption of light, or by accepting energy from an excited donor molecule (sensitizer), or by reacting with another chemical that has reached an excited state
      - b. Oxidation by ozone
      - c. Reaction with free radicals
      - d. Reactions with other chemical contaminants

Table F.3: Candidate Tests for Screening Ecological Impact of New Products (Conway, 1982).

I. **Chemical Fate (Transport, Persistence)**

- A. Transport
  - 1. Adsorption isotherm (soil)
  - 2. Partition coefficient (water/octanol)
  - 3. Water solubility
  - 4. Vapor pressure
- B. Other Physical–Chemical Properties
  - 1. Boiling/melting/sublimation points
  - 2. Density
  - 3. Dissociation constant
  - 4. Flammability/explodability
  - 5. Particle size
  - 6. pH
  - 7. Chemical incompatibility
  - 8. Vapor-phase UV spectrum for halocarbons
  - 9. UV and visible absorption spectra in aqueous solution
- C. Persistence
  - 1. Biodegradation
    - a. Shake flask procedure following carbon loss
    - b. Respirometric method following oxygen (BOD) and/or carbon dioxide
    - c. Activated sludge test (simulation of treatment plant)
    - d. Methane and CO_2 productions in anaerobic digestion
  - 2. Chemical degradation
    - a. Oxidation (free-radical)
    - b. Hydrolysis (25°C, pH 5.0 and 9.0)
  - 3. Photochemical transformation in water

II. Ecological Effects

- A. Microbial Effects
  - 1. Cellulose decomposition
  - 2. Ammonification of urea
  - 3. Sulfate reduction
- B. Plant Effects
  - 1. Algae inhibition (fresh and seawater, growth, nitrogen fixation)
  - 2. Duck weed inhibition (increase in fronds or dry weight)
  - 3. Seed germination and early growth
- C. Animal Effects Testing
  - 1. Aquatic invertebrates (*Daphnia*) acute toxicity (first instar)
  - 2. Fish acute toxicity (96 hr)
  - 3. Quail dietary LC_{50}
  - 4. Terrestial mammal test
  - 5. *Daphnia* life cycle test
  - 6. *Mysidopsis bahia* life cycle
  - 7. Fish embryo–juvenile test
  - 8. Fish bioconcentration test

RISK ASSESSMENT FOR HAZARDOUS WASTE DISPOSAL SITES

Existing and planned hazardous waste disposal sites are receiving increased attention as a result of the Resource Conservation and Recovery Act of 1976, and the "Superfund" Act of 1980. Environmental contamination has been documented at many existing sites. For example, the U.S. Environmental Protection Agency recently sponsored a study of damage case histories at 929 sites nationwide (Tusa and Gillen, 1982). Table F.4 contains a summary of guidelines used in rating the severity of damage at the evaluated sites. Many of the sites contained multiple facilities. A total of 1,722 individual facility types were used in describing the 929 sites in the ten regions. Of the 1,722 facility types evaluated, 23% were landfills, 22% were containers, 16% were surface impoundments and 11% were tanks. The remaining 28% of the facilities were described by various other categories. Contamination, either documented or suspected, was identified in 834 sites, or at 90% of the sites evaluated. At 555 of the sites, or 60%, contamination was documented. Most of the contamination occurred in ground water 32%, with the remaining incidents occurring to soil (31%), surface water (29%), and air (8%). The events most often associated with contamination included leachate, leaks, spills, fire/explosion, toxic gas emission and erosion. The most commonly identified contaminants included metals, volatile halogenated organics, and volatile non-halogenated organics.

A conceptual framework for preliminary site screening is shown in Figure F.10 (Unites, Possidento and Housman, 1980). The guidelines in Table F.4 could serve as a basis for ascertaining the severity of damage

Table F.4: Summary of Guidelines Used in Rating Severity of Damage at Evaluated Sites (Tusa and Gillen, 1982).

Category	Severity		
	High	Medium	Low
Human Health	Damage incident to at least one person resulting in ...		
	...death	...severe injury	...minor injury
		Contamination of groundwater resulting in closure or restriction of drinking water in a ...	
		...community water supply	...single private well
Environmental			
groundwater, surface water & air	Contamination incident where sampling indicates the presence of pollutants in concentrations ...		
	...at levels greater than 10 times applicable standards	...at levels equal to applicable standards	...at detectable levels, but less than applicable standards
food chain, flora	Contamination incident resulting in stress to vegetated or food crop area ...		
	...greater than one acre	...greater than 1/2 acre	...in limited areas only
fauna	Damage incident confirmed by ...		
	...massive kills	...limited kills	...bioassay studies confirming tissue contamination
soil	[1]	[1]	...contamination incident confirmed by sampling data

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[1] Higher levels of damage were typically identified via use of evidence in the other categories.

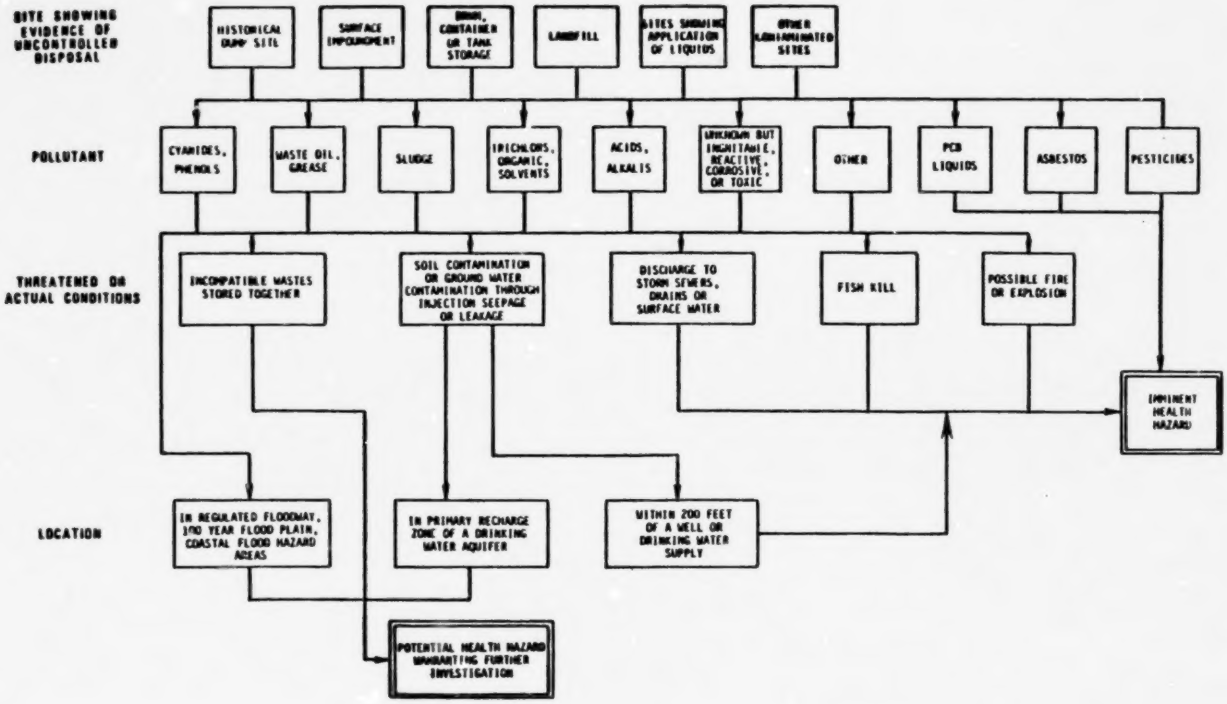
SITE SHOWING EVIDENCE OF UNCONTROLLED DISPOSAL
HISTORICAL DUMP SITE
SURFACE IMPOUNDMENT
DRUM, CONTAINER OR TANK STORAGE
LANDFILL
SITES SHOWING APPLICATION OF LIQUIDS
OTHER CONTAMINATED SITES
POLLUTANT
CYANIDES, PHENOLS
WASTE OIL, GREASE
SLUDGE
TRICHLORS, ORGANIC, SOLVENTS
ACIDS, ALKALIS
UNKNOWN BUT IGNITABLE, REACTIVE, CORROSIVE, OR TOXIC
OTHER
PCB LIQUIDS
ASBESTOS
PESTICIDES
THREATENED OR ACTUAL CONDITIONS
INCOMPATIBLE WASTES STORED TOGETHER
SOIL CONTAMINATION OR GROUND WATER CONTAMINATION THROUGH INJECTION SEEPAGE OR LEAKAGE
DISCHARGE TO STORM SEWERS, DRAINS OR SURFACE WATER
FISH KILL
POSSIBLE FIRE OR EXPLOSION
IMMINENT HEALTH HAZARD
LOCATION
IN REGULATED FLOODWAY, 100 YEAR FLOOD PLAIN, COASTAL FLOOD HAZARD AREAS
IN PRIMARY RECHARGE ZONE OF A DRINKING WATER AQUIFER
WITHIN 200 FEET OF A WELL OR DRINKING WATER SUPPLY
POTENTIAL HEALTH HAZARD WARRANTING FURTHER INVESTIGATION

Figure F.10: Preliminary Site Evaluation Assessment Schematic (Unites, Possidento, and Housman, 1980).

at a site. Nisbet (1982) identified the following seven steps for a qualitative risk assessment at a hazardous waste site:

(1) An engineering survey of the site, including an assessment of the propensity for scheduled and unscheduled releases;

(2) An inventory of the materials stored or disposed of at the site;

(3) An assessment of geological, hydrogeological and meteorological data, to assess the propensity for transport of materials away from the site (see Figure F.11 for information on the migration of hazardous wastes in the environment (Murphy, 1982).

(4) A monitoring program for ground water, air, and other media, to measure the ambient concentrations of chemicals being transported away from the site;

(5) A survey of the distribution of the human population and other sensitive targets subject to exposure;

(6) A review of the toxicity of each of the major components of the material subject to release;

(7) Finally, an assessment of potential risks resulting from the exposure, including characterization of the uncertainty in this assessment.

Unless a very detailed monitoring program is carried out, it is rarely possible for the above 7-step assessment to be quantitatively reliable. In many cases, the risk assessor has to settle for much less -- often a ranking or scoring procedure for factors controlling inherent hazard, release, environmental transport, and population at risk. At best, such a procedure can yield a ranking of risk on a qualitative or semi-quantitative scale; for example, on a scale from 1-10, or from "low" to "high". This is sufficient for many purposes -- e.g., for priority setting, for permitting, or for decisions on loss control programs or insurance (Nisbet, 1982).

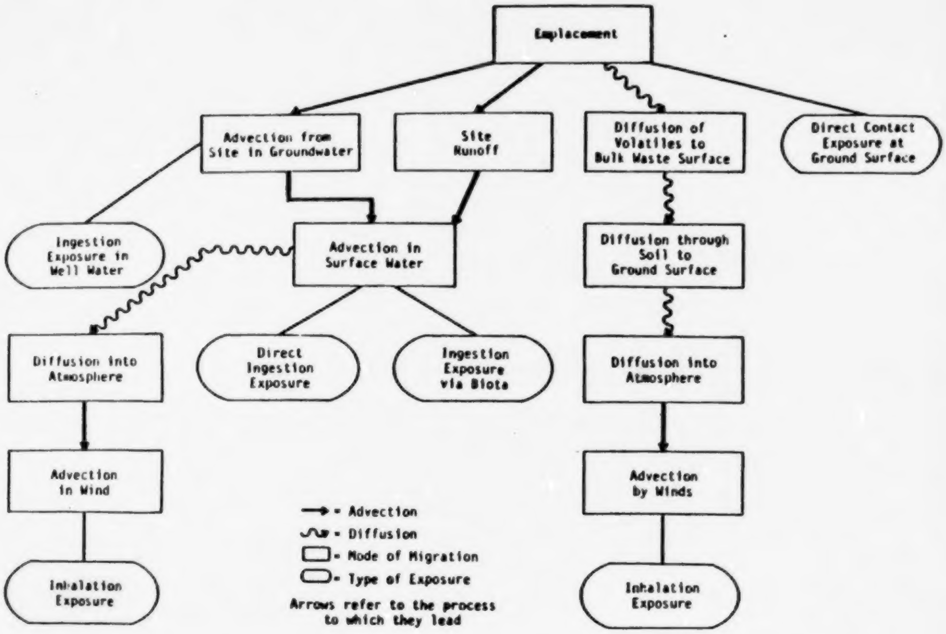
Emplacement
Advection from Site in Groundwater
Site Runoff
Diffusion of Volatiles to Bulk Waste Surface
Direct Contact Exposure at Ground Surface
Ingestion Exposure in Well Water
Advection in Surface Water
Diffusion through Soil to Ground Surface
Diffusion into Atmosphere
Direct Ingestion Exposure
Ingestion Exposure via Biota
Diffusion into Atmosphere
Advection in Wind
Advection by Winds
Inhalation Exposure
Inhalation Exposure
→ = Advection
⁓ = Diffusion
▭ = Mode of Migration
⬭ = Type of Exposure
Arrows refer to the process to which they lead

Figure F.11: Sample Diagram for Migration of Hazardous Wastes in the Environment (Murphy, 1982)

Two numerical-based scoring procedures and one health effects criteria-based system will be described as examples for assessing the risks of hazardous waste disposal sites, including the Hazard Ranking System (Caldwell, Barrett and Chang, 1981), the Site Rating Methodology (Kufs, et al., 1980), and the Air Quality Risk Assessment System (Walsh and Jones, 1982).

Hazard Ranking System

The U.S. Environmental Protection Agency, through a contract with MITRE Corporation, developed the Hazard Ranking System (HRS) as a method for ranking facilities for remedial action according to risks to health and the environment (Caldwell, Barrett and Chang, 1981). The HRS is a scoring system designed to address the full range of problems resulting from releases of hazardous substances, including surface water, air, fire and explosion, and direct contact, in addition to ground water contamination. The HRS applies a structured value analysis approach. Three migration routes of exposure, ground water, surface water and air are evaluated and their scores are combined to derive a score representing the relative risk posed by the facility. Two additional routes of exposure, (1) fire and explosion and (2) direct contact, are measures of the need for emergency response.

Application of the HRS results in three scores for a hazardous waste facility. One score, S_M, reflects the potential for harm to humans or the environment as a result of migration of a hazardous substance away from the facility by routes involving ground water, surface water or air. S_M is a composite of separate scores for each of the three routes. Another score, S_{FE}, reflects the potential for harm from materials that can explode or cause fires. The third, S_{DC}, reflects the potential for harm as a result of direct human contact with hazardous materials at the facility (i.e., no migration need be involved). The score for each hazard mode (migration, fire and explosion, and direct contact) or route is obtained by considering a set of factors that characterize the hazardous potential of the facility. A comprehensive listing of factors for all of the hazard modes is given in Table F.5 (Caldwell, Barrett and Chang, 1981). Each factor is assigned a numerical value (generally on a scale of 0 to 3, 5 or 8) according to prescribed guidelines. This value is then multiplied by a weighting factor to yield the factor score. The factor scores are then combined by following established guidelines: scores within a factor category are additive but the factor category scores are multiplicative.

In computing S_{FE} or S_{DC}, or an individual migration route score, the product of its factor category scores is divided by the maximum value the product can have and the resulting ratio is multiplied by 100, thus normalizing scores to a 100-point scale. Computation of S_M is slightly more complex since S_M is a composite of the scores for the three possible routes: ground water (S_{gw}), surface water (S_{sw}) and air (S_a). S_M is obtained from the equation:

$$S_M = \frac{1}{1.73}\sqrt{S_{gw}^2 + S_{sw}^2 + S_a^2}$$

The factor 1/1.73 arises from the vector addition of the three route scores after the individual scores are normalized to a common denominator. This means of combining them gives added weight to routes with higher scores.

Table F.5: Comprehensive List of Rating Factors in Hazard Ranking System (Caldwell, Barrett, and Chang, 1981).

HAZARD MODE	FACTOR CATEGORY	FACTORS		
Migration		Ground Water Route	Surface Water Route	Air Route
	Containment	• Containment	• Containment	
	Route Characteristics	• Depth to aquifer of concern • Net precipitation • Permeability of unsaturated zone	• Site slope and interviewing terrain • 1 Year 24 hour rainfall • Distance to nearest surface water • Flood potential	
	Waste Characteristics	• Physical State • Persistence • Toxicity	• Physical State • Persistence • Toxicity	• Volatility/Physical State • Reactivity • Incompatibility • Toxicity
	Hazardous Waste Quantity	• Total waste quantity	• Total waste quantity	• Total waste quantity
	Targets	• Ground water use • Distance to nearest well down gradient • Population served by ground water drawn with 3 mile radius	• Surface water use • Distance to a sensitive environment • Population served by surface water drawn within 3 mile radius	• Distance to nearest human population • Population within 1 mile radius • Distance to sensitive environment • Land use
Fire and Explosion	Containment	• Containment		
	Waste Characteristics	• Direct evidence of ignitibility or explosivity • Ignitibility • Reactivity • Incompatibility		
	Hazardous Waste Quantity	• Total waste quantity		
	Targets	• Distance to nearest human population • Distance to nearest building • Distance to sensitive environment • Land use • Population within 2 mile radius • Number of buildings within 2 mile radius		
Direct Contact	Accessibility	• Accessibility		
	Containment	• Containment		
	Waste Characteristics	• Toxicity		
	Targets	• Population within a 1 mile radius • Distance to a critical habitat		

The HRS does not result in quantitative estimates of the probability of harm from a facility or the magnitude of the harm that could result. Rather, it is a device for rank-ordering facilities in terms of the potential hazard they present. Risks are generally considered to be a function of the probability of an event occurring and the magnitude or severity should the event occur. Applying this approach to hazardous substance facilities, the probability and magnitude of a release are generally functions of the following areas:

- The manner in which the hazardous material is contained
- The route by which its release would occur
- The characteristics of the harmful substance
- The amount of hazardous substance
- The likely targets

These areas have been examined and representative factors were chosen to address each in the HRS (Caldwell, Barrett and Chang, 1981).

Site Rating Methodology

The Site Rating Methodology (SRM) has been used for the prioritization of "Superfund" sites in terms of remedial actions. The SRM has three elements: (1) a system for rating the general hazard potential of a site, (2) a system for modifying the general rating based on site-specific problems, and (3) a system for interpreting the ratings in meaningful terms. The first element is called the Rating Factor System, the second is called the Additional Points System, and the third is called the Scoring System (Kufs, et al., 1980). The Rating Factor System is used for the initial rating of a waste disposal site based on a set of 31 generally applicable rating factors. As shown in Table F.6, the 31 factors have been divided into four categories based on their focus. The four categories are: (1) receptors, (2) pathways, (3) waste characteristics, and (4) waste management practices. For each of the factors, a four-level rating scale has been developed which provides factor-specific levels ranging from "0" (indicating no potential hazard) to "3" (indicating a high potential hazard). The rating scales are also listed in Table F.6. These scales have been defined so that the rating factors can typically be evaluated on the basis of readily available information from published materials, public and private records, contacts with knowledgeable parties or site visits.

The rating factors do not all assess the same magnitude of potential environmental impact. Consequently, a numerical value called a multiplier has been assigned to each factor in accordance with the relative magnitude of impact that it does assess. Multipliers were originally defined based on the judgment of individuals from several technical disciplines and were revised based on the results of field testing. These values are multiplied by the appropriate factor ratings to result in factor scores for each of the rating factors.

The Additional Points System addresses special features of a facility's location, design or operation that cannot be handled satisfactorily by rating factors alone (Kufs, et al., 1980). These features might present hazards that are unusually serious, unique to the site, or not assessable by rating scales. For example, an extremely high population density near a site should be considered even more hazardous than the rating factor for "population within 1,000 ft."

Table F.6: Rating Factors and Scales for the Site Rating Methodology (Kufs, et al., 1980).

RATING FACTORS	RATING SCALE LEVELS			
	0	1	2	3
RECEPTORS				
POPULATION WITHIN 1,000 FEET	0	1 TO 25	26 TO 100	GREATER THAN 100
DISTANCE TO NEAREST DRINKING-WATER WELL	GREATER THAN 3 MILES	1 TO 3 MILES	3,001 FEET TO 1 MILE	0 TO 3,000 FEET
DISTANCE TO NEAREST OFF-SITE BUILDING	GREATER THAN 2 MILES	1 TO 2 MILES	1,001 FEET TO 1 MILE	0 TO 1,000 FEET
LAND USE/ZONING	COMPLETELY REMOTE (ZONING NOT APPLICABLE)	AGRICULTURAL	COMMERCIAL OR INDUSTRIAL	RESIDENTIAL
CRITICAL ENVIRONMENTS	NOT A CRITICAL ENVIRONMENT	PRISTINE NATURAL AREAS	WETLANDS, FLOODPLAINS, AND PRESERVED AREAS	MAJOR HABITAT OF AN ENDANGERED OR THREATENED SPECIES
PATHWAYS				
EVIDENCE OF CONTAMINATION	NO CONTAMINATION	INDIRECT EVIDENCE	POSITIVE PROOF FROM DIRECT OBSERVATION	POSITIVE PROOF FROM LABORATORY ANALYSES
LEVEL OF CONTAMINATION	NO CONTAMINATION	LOW LEVELS, TRACE LEVELS, OR UNKNOWN LEVELS	MODERATE LEVELS OR LEVELS THAT CANNOT BE SENSED DURING A SITE VISIT BUT WHICH CAN BE CONFIRMED BY A LABORATORY ANALYSIS	HIGH LEVELS OR LEVELS THAT CAN BE SENSED EASILY BY INVESTIGATORS DURING A SITE VISIT
TYPE OF CONTAMINATION	NO CONTAMINATION	SOIL CONTAMINATION ONLY	BIOTA CONTAMINATION	AIR, WATER, OR FOODSTUFF CONTAMINATION
DISTANCE TO NEAREST SURFACE WATER	GREATER THAN 5 MILES	1 TO 5 MILES	1,001 FEET TO 1 MILE	0 TO 1,000 FEET
DEPTH TO GROUNDWATER	GREATER THAN 100 FEET	51 TO 100 FEET	21 TO 50 FEET	0 TO 20 FEET
NET PRECIPITATION	LESS THAN -10 INCHES	-10 TO +5 INCHES	+5 TO +20 INCHES	GREATER THAN +20 INCHES
SOIL PERMEABILITY	GREATER THAN 50% CLAY	30% TO 50% CLAY	15% TO 30% CLAY	0 TO 15% CLAY
BEDROCK PERMEABILITY	IMPERMEABLE	RELATIVELY IMPERMEABLE	RELATIVELY PERMEABLE	VERY PERMEABLE
DEPTH TO BEDROCK	GREATER THAN 60 FEET	31 TO 60 FEET	11 TO 30 FEET	0 TO 10 FEET

Table F.6: (continued)

RATING FACTORS	RATING SCALE LEVELS			
	0	1	2	3
WASTE CHARACTERISTICS				
TOXICITY	SAX'S LEVEL 0 OR NFPA'S LEVEL 0	SAX'S LEVEL 1 OR NFPA'S LEVEL 1	SAX'S LEVEL 2 OR NFPA'S LEVEL 2	SAX'S LEVEL 3 OR NFPA'S LEVELS 3 OR 4
RADIOACTIVITY	AT OR BELOW BACKGROUND LEVELS	1 TO 3 TIMES BACKGROUND LEVELS	3 TO 5 TIMES BACKGROUND LEVELS	OVER 5 TIMES BACKGROUND LEVELS
PERSISTENCE	EASILY BIODEGRADABLE COMPOUNDS	STRAIGHT CHAIN HYDROCARBONS	SUBSTITUTED AND OTHER RING COMPOUNDS	METALS, POLYCYCLIC COMPOUNDS, AND HALOGENATED HYDROCARBONS
IGNITABILITY	FLASH POINT GREATER THAN 200° OR NFPA'S LEVEL 0	FLASH POINT OF 140°F. to 200°F. OR NFPA'S LEVEL 1	FLASH POINT OF 80°F. TO 140°F. OR NFPA'S LEVEL 2	FLASH POINT LESS THAN 80°F. OR NFPA'S LEVELS 3 OR 4
REACTIVITY	NFPA'S LEVEL 0	NFPA'S LEVEL 1	NFPA'S LEVEL 2	NFPA'S LEVELS 3 OR 4
CORROSIVENESS	pH OF 6 TO 9	pH OF 5 TO 6 OR 9 TO 10	pH OF 3 TO 5 OR 10 TO 12	pH OF 1 TO 3 OR 12 TO 14
SOLUBILITY	INSOLUBLE	SLIGHTLY SOLUBLE	SOLUBLE	VERY SOLUBLE
VOLATILITY	VAPOR PRESSURE LESS THAN 0.1 mm Hg	VAPOR PRESSURE OF 0.1 TO 25 mm Hg	VAPOR PRESSURE OF 78 TO 25 mm Hg	VAPOR PRESSURE GREATER THAN 78 mm Hg
PHYSICAL STATE	SOLID	SLUDGE	LIQUID	GAS
WASTE MANAGEMENT PRACTICES				
SITE SECURITY	SECURE FENCE WITH LOCK	SECURITY GUARD BUT NO FENCE	REMOTE LOCATION OR BREACHABLE FENCE	NO BARRIERS
HAZARDOUS WASTE QUANTITY	0 TO 250 TONS	251 TO 1,000 TONS	1,001 TO 2000 TONS	GREATER THAN 2,000 TONS
TOTAL WASTE QUANTITY	0 TO 10 ACRE FEET	11 TO 100 ACRE FEET	101 TO 250 ACRE FEET	GREATER THAN 250 ACRE FEET
WASTE INCOMPATIBILITY	NO INCOMPATIBLE WASTES ARE PRESENT	PRESENT, BUT DOES NOT POSE A HAZARD	PRESENT AND MAY POSE A FUTURE HAZARD	PRESENT AND POSING AN IMMEDIATE HAZARD
USE OF LINERS	CLAY OR OTHER LINER RESISTENT TO ORGANIC COMPOUNDS	SYNTHETIC OR CONCRETE LINER	ASPHALT-BASE LINER	NO LINER USED
USE OF LEACHATE COLLECTION SYSTEMS	ADEQUATE COLLECTION AND TREATMENT	INADEQUATE COLLECTION OR TREATMENT	INADEQUATE COLLECTION AND TREATMENT	NO COLLECTION OR TREATMENT
USE OF GAS COLLECTION SYSTEMS	ADEQUATE COLLECTION AND TREATMENT	COLLECTION AND CONTROLLED FLARING	VENTING OR INADEQUATE TREATMENT	NO COLLECTION OR TREATMENT
USE AND CONDITION OF CONTAINERS	CONTAINERS ARE USED AND APPEAR TO BE IN GOOD CONDITION	CONTAINERS ARE USED BUT A FEW ARE LEAKING	CONTAINERS ARE USED BUT MANY ARE LEAKING	NO CONTAINERS ARE USED

indicates. Power lines running through sites that contain explosive or flammable wastes, though not typical of waste disposal sites in general, should be considered a potential hazard. Finally, the function of the nearest off-site building might indicate a serious threat of human exposure exists, even though types of functions cannot be quantitatively evaluated by rating scales the way distance can be. In such cases, raters can assign a greater hazard potential score to a site than it might otherwise receive by using the Additional Points System. Guidance on suggested point assignments are in Table F.7 (Kufs, et al., 1980). In order to maintain the objectivity of the rating methodology while allowing the assignment of additional points, the following limits have been placed on the number of additional points that can be assigned in each rating factor category: Receptors, 50 points; Pathways, 25 points; Waste characteristics, 20 points; and Waste management practices, 30 points.

The Scoring System is based on all rating factors and additional points that are used to rate a site. Each subscore is based on those rating factors and additional points in that factor category which are used to rate a site. All of these scores are normalized so that they are on a scale of 0 to 100. Associated with every hazard potential score is a percentage of missing and assumed data. These percentages highlight scores that are based on large amounts of missing data and, in a general way, measure the reliability of the scores (Kufs, et al., 1980).

Once a site has been rated using the SRM, the scores must be interpreted. Assessing the meaning of a score can be approached by

Table F.7: Guidance for Additional Points System in the Site Rating Methodology (Kufs, et al., 1980).

Example Situation	**Suggested Point Allotment**
	Receptors (50 Points Maximum)
• Use of site by nearby residents, expecially children (for example, a site may be remote and/or fenced, but may still be used frequently by children as a play area or by adults with recreational vehicles).	• 0 to 4 points if used sparingly by adults; 4 to 10 points if used regularly by adults; 10 to 20 points if used regularly by children.
• Type of building nearby, (for example, a school versus a warehouse).	• 0 to 6 points for public use buildings (e.g., shopping centers); 5 to 15 points for schools and hospitals.
• Presence of major surface water supplies, aquifers, or aquifer recharge areas near the site.	• 0 to 30 points depending on the proximity of the drinking water supply and the extent to which it is used.
• Type of adjacent land use (for example, dairy farms, meat packing plants, orchards, and municipal water treatment plants would cause extreme concern).	• 0 to 10 points for recreational uses; 10 to 30 points for food or water-related uses.
• Presence of economically important natural resources (e.g., shellfish beds, agricultural lands).	• 0 to 20 points depending on the number of people affected.
• Presence of major transportation routes.	• 0 to 2 points for railways; 2 to 6 points for roads; and 4 to 1 points for foot paths or bicycle trails.
• Residential population within 1,000 feet over 100 people.	• 1 point per 25 people up to 10 points.
	Pathways (25 Points Maximum)
• Erosion and runoff; susceptibility to washout from a flood; and slope instability.	• 0 to 4 points if a potential problem; 4 to 8 points if a moderate problem; 8 to 12 points if a severe problem.
• Seismic activity.	• 0 to 10 points depending on the most likely adverse effects.
	Waste Characteristics (20 Points Maximum)
• Substances that are carcinogenic, teratogenic, or mutagenic.	• 4 points per substance.
• Any high-level radioactive wastes.	• 5 points if in minute quantities; 15 points if in significant quantities.
• Substances with a high bioaccumulation potential.	• 2 points per substance.
• Substances that are infectious.	• 0 to 5 points for wastes containing known transmittable pathogens depending on the potency of the wastes.
	Waste Management Practices (30 Points Maximum)
• No training or safety measures for personnel (active sites).	• 0 to 4 points depending on the number of people and their responsibilities.
• Open burning (active sites).	• 0 to 10 points depending on regularity of the practice and the type of waste burned.
• Site abandonment.	• 0 to 5 points depending on the reasons for the abandonment.
• No waste mapping or records.	• 0 to 8 points depending on the presence of hazardous or incompatible wastes.
• Heat sources or power lines near areas having explosives or flammable wastes.	• 0 to 8 points depending on the proximity and potential for ignition.
• Less than 18 inches of cover over inactive landfills.	• 0 to 4 points for no apparent problems; 4 to 8 points for blowing trash; 6 to 12 points for hazardous vapors.
• Less than 6 inches of daily cover on active landfills.	• 0 to 2 points for no apparent problems; 2 to 4 points for blowing trash; 3 to 6 points for hazardous vapors.
• Total quantity of waste over 250 acre-feet.	• 1 point per 10 acre-feet up to 15 points.
• Quantity of hazardous waste over 2000 tons (2370 cubic yards).	• 1 point per 4000 tons (4750 cubic yards) up to 25 points.

either relative or absolute interpretation (Kufs, et al., 1980). Relative interpretations are made by means of rankings. When a number of sites all require attention, rankings can be used to determine a preferential ordering. For example, when there are too many facilities to be addressed with available resources, rankings can be used to help determine the order of sites for: collection of additional background information; surveys of sites; complete investigations of sites; implementation of remedial actions; and preparation of enforcement cases. Sites can be ranked in several ways including by overall scores, subscores, combinations of scores, and percentages of missing data. Overall scores are likely to be the most useful basis for ranking waste sites because all rating factors are included in the score. The subscores, however, may also provide valuable rankings. A scale developed for absolute interpretations can be used as a convenient point of reference for deciding "how bad is bad" at a site, and as a tool for deciding how urgent it is to respond to the problems at a site (Kufs, et al., 1980). For example, Figure F.12 is a flexible scale for overall hazard potential scores that can be used as a guide for defining absolute levels of hazard. Based on this use of hazard potential scores, a rater might decide to pursue in-depth investigations of sites classified high and very high before making initial surveys of sites classified very low and low.

Air Quality Risk Assessment System

There are three steps in remedial action planning in which air exposure risks must be considered, both from a health impact and a

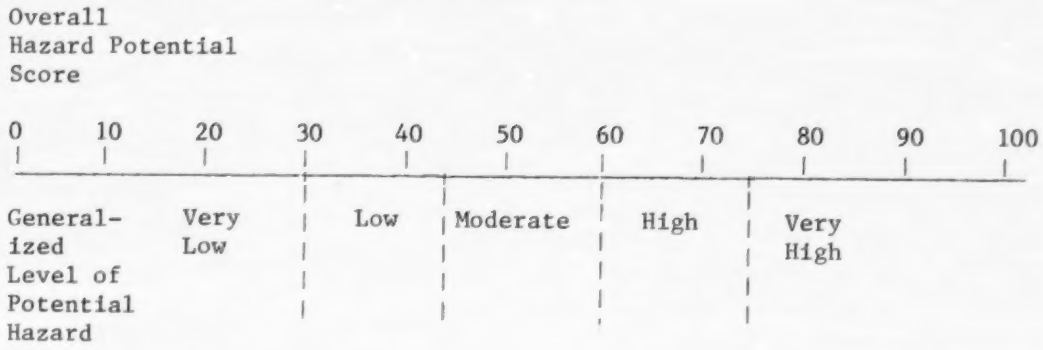
Overall
Hazard Potential
Score
0
10
20
30
40
50
60
70
80
90
100
Generalized Level of Potential Hazard
Very Low
Low
Moderate
High
Very High

Figure F.12: Guidelines for Interpreting the Level of Potential Hazard Based on the Site Rating Methodology (Kufs, et al., 1980)

liability point of view (Walsh and Jones, 1982). The first is an assessment of the present off-site risk before any type of action is considered since air risk considerations may be a remedial action design factor. This assessment would include an analysis of any existing air quality impact data. The second major task is associated with the potential air quality impacts of remedial action alternatives. An air risk assessment of the candidate alternatives must be undertaken to predict the ramifications of whichever cleanup alternative is chosen. Technical alternatives which have potential air risks may include: physical removal operations; air or steam stripping operations; chemical stabilization; and on-site combustion. Most remedial action alternatives are likely to increase the exposure risk in the short-term, so this increase must be monitored and controlled by instituting operational practices to minimize off-site exposures. The final phase of a complete air quality risk assessment deals with post-closure considerations. This would primarily consist of continued area monitoring over a short period of time where air risks were clearly identified as a remedial action problem. The purpose of this monitoring is to document the fact that air risks have been reduced to acceptable levels. This is an additional liability prevention step.

A basic aspect of the Air Quality Risk Assessment System is the use of criteria to determine when a risk level is, or is not, present (Walsh and Jones, 1982). There is a good deal of uncertainty as to which effects criteria should be used especially when it relates to cancer risk. Examples of criteria used to evaluate the range of risk levels include:

Cancer Assessment Group Values (CAGs). These are recommended lifetime exposure limits to known carcinogens which have been developed by the U.S. Environmental Protection Agency for a limited number of toxic compounds. The CAG number represents maximum allowable concentrations that may result in incremental risk of human health over the short-term or long-term at an assumed risk. This assumed risk is the expected number of increased incidences of cancer in the effected population when the concentration over a lifetime equals the specified value.

Multimedia Environmental Goals (MEGs). The MEGs were developed in recent years by the Research Triangle Institute for the U.S. Environmental Protection Agency to meet the need for a workable system of evaluating and ranking pollutants for the purpose of multimedia environmental impact assessment. Consideration in arriving at these ambient level goals was given to existing Federal standards or criteria, established or estimated human threshold levels, and acceptable risk levels for lifetime human exposure to suspected carcinogens or teratogens, among others.

Threshold Limit Value (TLV). TLVs are established by the American Conference of Governmental Industrial Hygienists as guidelines for prevention of adverse occupational exposures and are based on both animal studies and epidemiological findings and inferences. They refer to airborne concentrations of substances and represent conditions under which it is believed that nearly all workers may be repeatedly exposed for eight hours a day, five days a week, without adverse effects. Many TLVs also protect against short-term aggravations such as eye irritation, odor impacts, headache, etc. However, TLVs do not represent the hypersusceptible minority of individuals. Additionally, by definition, they assume a daily period (non-working hours) of non-exposure time. Many states have developed or are currently developing ambient air hazardous waste guidelines and regulations based on these TLVs. A common practice is to adjust the TLV for a 24 hr exposure and then divide by some large uncertainty factor. Common limits are TLV/300 - TLV/420.

SUMMARY

Risk assessment is a currently popular term being used to describe both risk quantification followed by risk evaluation. A confusing issue is the non-standardization of terminology. Completion of risk assessments is often hampered by lack of understanding of risk paths and by lack of historical data. Environmental risk assessment encompasses the transport and fate of pollutants in the environment and their subsequent effects on human and nonhuman receptors. Due to limitations of data, relative risk approaches are often used. Examples have been presented for risk assessments for hazardous waste sites.

In conclusion, risk assessment is a young, but maturing, field of endeavor. Needs and anticipated changes in the near term include:

(1) Standardization of terminology.

(2) Development of approaches to address probabilities of occurrences.

(3) Delineation of risk paths.

(4) Standardization of risk evaluation approaches.

(5) Field testing and further development of risk scoring or rating methodologies.

(6) Aggregation of risk estimation factors for addressing a variety of activities.

SELECTED REFERENCES

Berger, I.S., "Determination of Risk for Uncontrolled Hazardous Waste Sites", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1982, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 23-26.

Caldwell, S., Barrett, K.W. and Chang, S.S., "Ranking System for Releases of Hazardous Substances", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1981, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 14-20.

Conway, R.A., "Introduction to Environmental Risk Analysis", Ch. 1 in Environmental Risk Analysis for Chemicals, R.A. Conway, editor, 1982, Van Nostrand Reinhold Company, New York, New York, pp. 1-30.

Cornaby, B.W., et al., "Application of Environmental Risk Techniques to Uncontrolled Hazardous Waste Sites", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1982, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 380-384.

Ess, T.H. and Shih, C.S., "Perspectives of Risk Assessment for Uncontrolled Hazardous Waste Sites", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1982, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 390-395.

Inhaber, H., Energy Risk Assessment, 1982, Gordon and Breach Science Publishers, Inc., New York, New York, pp. 1-54.

Jutro, P.R. and Nerode, A., "Development of Methodology for Determining Risk Assessment When Sludge is Applied to Land", EPA-600/S1-81-058, Aug. 1981, U.S. Environmental Protection Agency, Cincinnati, Ohio.

Kufs, C., et al., "Rating the Hazard Potential of Waste Disposal Facilities", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1980, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 30-41.

Lee, W.W. and Nair, K., "Risk Quantification and Risk Evaluation", Proceedings of National Conference on Hazardous Material Risk Assessment, Disposal and Management, 1979, Information Transfer, Inc., Silver Spring, Maryland, pp. 44-48.

Murphy, B.L., "Abandoned Site Risk Assessment Modeling and Sensitivity Analysis", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1982, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 396-398.

Nisbet, I.C., "Uses and Limitations of Risk Assessments in decision-Making on Hazardous Waste Sites", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1982, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 406-407.

Schweitzer, G.E., "Risk Assessment Near Uncontrolled Hazardous Waste Sites: Role of Monitoring Data", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1981, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 238-247.

Shih, C.S. and Ess, T.H., "Multiattribute Decision-Making Imbedded with Risk Assessment for Uncontrolled Hazardous Waste Sites", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1982, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 408-413.

Tusa, W.K. and Gillen, B.D., "Assessment of Hazardous Waste Mismanagement Cases", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1982, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 27-30.

Unites, D., Possidento, M. and Housman, J., "Preliminary Risk Evaluation for Suspected Hazardous Waste Disposal Sites in Connecticut", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1980, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 25-29.

Walsh, J.F. and Jones, K.H., "The Air Quality Impact Risk Assessment Aspects of Remedial Action Planning", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1982, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 63-66.

APPENDIX G

ANNOTATED BIBLIOGRAPHY FOR AQUIFER RESTORATION

This appendix contains the abstracts of 225 references on both general and specific aspects of aquifer restoration. The contained references were identified via computer-based literature searches, planning and attendance at technical conferences, and personal contacts. The references are presented in alphabetical order by author. Due to the fact that some references address multiple aquifer restoration technologies, no classification of the contained references by technology has been developed.

Absalon, J.R. and Hockenbury, M.R., "Treatment Alternatives Evaluation for Aquifer Restoration", Proceedings of the Third National Symposium on Aquifer Restoration and Ground Water Monitoring, 1983, National Water Well Association, Worthington, Ohio, pp. 98-104.

This paper describes the essential steps necessary to adequately define a ground water contamination problem and then evaluate the technically feasible treatment alternatives from a performance, cost and O&M point of view. The approach described is based on actual field studies conducted in the last two years and the recommended solutions for a number of similar problems. The first critical step in solving a ground water contamination problem is the quantitative identification of the extent and nature of the problem. The primary objectives of the identification phase include:

- Define site environmental setting
  - -- Surface
  - -- Subsurface
- Locate potential contaminant sources
- Define potential contaminant migration pathways
- Determine contaminant extent and concentration

Given the ground water contamination information collected in the first phase of work, the study should proceed to an identification of treatment alternatives which may be useful for rehabilitating the aquifer. These would typically include physical, chemical, biological or other treatment processes depending on the chemical characteristics of the contaminated water and the level of treatment desired. Candidate treatment processes in each of the four categories which would be considered include:

- Physical treatment
    - -- Phase separation
    - -- Filtration
    - -- Gravity sedimentation
- Chemical or combined physical/chemical treatment
    - -- Chemical coagulation
    - -- pH adjustment
    - -- Carbon adsorption (liquid and vapor phase)
    - -- Air stripping
    - -- Stream stripping
    - -- Resin adsorption
    - -- Chemical oxidation
- Biological treatment
    - -- Aerobic fixed film
    - -- Aerobic suspended growth
    - -- Anaerobic
- Residuals treatment
    - -- Incineration
    - -- Sludge thickening/dewatering
    - -- Chemical recovery/reuse

Once the candidate treatment alternatives are identified, then bench- or pilot-scale treatability studies would be conducted to establish design criteria for the various treatment processes. These data will also demonstrate the performance capabilities of the various candidate treatment processes. In this paper, previously observed effectiveness on removal of organics (e.g., chlorinated solvents, hydrocarbons, etc.) will be presented for each treatment process. The results of these treatability studies are then used to develop a conceptual treatment process for the specific problem.

Adams, W.R., Jr. and Atwell, J.S., "A Dual Purpose Cleanup at a Superfund Site", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1983, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 352-353.

In this paper, the authors discuss the successful results generated by cooperative efforts between two state agencies, one faced with the need to construct a highway over a Superfund site and another responsible for the cleanup of that site. Also addressed are the engineering consultant's assessment of remedial alternatives and subsequent selection of the most cost-effective and environmentally sound solution to the problem posed by the construction. The hazardous waste site is the Pine Street Canal site in Burlington, Vermont, which was designated as Vermont's priority Superfund site because of its proximity to both business and residential areas and because of its location adjacent to Lake Champlain -- the city's source of drinking water.

Alexander, W.J., Miller, D.G., Jr. and Seymour, R.A., "Mitigation of Subsurface Contamination by Hydrocarbons", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1982, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 107-110.

Subsurface contamination by hydrocarbons is a recurring problem. Sources range from home-fuel tanks to terminals and transcontinental pipelines. Subsurface releases may go undetected for months or years. An understanding of the various transport phenomena is beneficial in developing initial working hypotheses for a given site. Site-specific definition of the extent of contamination is ultimately necessary, however, for implementing cost-effective mitigative measures. In this paper, the authors describe two cases involving hydrocarbon leaks from terminals which have substantially different hydrogeological settings nad consequently required different approaches for evaluation and mitigation.

Allen, R.D. and Parmele, C.S., "Treatment Technology for Removal of Dissolved Gasoline Components from Ground Water", Proceedings of the Third National Symposium on Aquifer Restoration and Ground Water Monitoring, 1983, National Water Well Association, Worthington, Ohio, pp. 51-59.

IT Enviroscience has conducted a technical and economic evaluation of technologies for removal of dissolved gasoline components from ground water. The components considered were benzene, toluene, xylene, ethylbenzene, t-butyl alcohol and methyl t-butyl ether. In an earlier literature search and evaluation, activated carbon adsorption and air stripping (or a combination of these technologies) were identified as the most likely treatment alternatives. IT Enviroscience conducted laboratory evaluations of these technologies in order to identify optimum design conditions. Activated carbon adsorption was evaluated over a range of feed concentrations, hydraulic loadings and regeneration conditions. The technology of steam regeneration was evaluated for regeneration of activated carbon used in this application. Air stripping was evaluated over a range of feed concentrations, temperatures and gas/liquid ratios. This paper describes the results of the laboratory evaluations and identifies the optimum design and operating conditions, It shows the relative treatment and cost effectiveness of the carbon adsorption and air stripping technologies and combinations thereof for removing dissolved gasoline components from ground water.

Althoff, W.F., Cleary, R.W. and Roux, P.H., "Aquifer Decontamination for Volatile Organics: A Case History", Ground Water, Vol. 19, No. 5, Sept.-Oct. 1981, pp. 445-504.

Organic solvents, including 1,1,1-trichloroethane at concentrations up to 40,000 ppb, were detected in the Old Bridge aquifer under an industrial plant in South Brunswick Township, New Jersey. A hydrogeologic investigation defined the ground water flow system and a plume of contamination which extended, at a concentration of at least 100 ppb, for a distance of about 1000 feet downgradient of the plant. A contamination abatement system was designed and installed to prevent this plume from reaching a municipal well located about 2500 feet from the site. The system includes seven extraction wells and a water treatment facility. The locations of the extraction wells and their combined pumping rate were determined in part by a computer simulation of the aquifer, which was subsequently checked by a 20-day pumping test of the system. The on-site treatment facility uses two cooling towers in series to air-strip the volatile organics, and two infiltration ponds to return the treated water to the aquifer. The abatement system has been operating for about 10 months. Groundwater monitoring results show that the plume is now significantly smaller and less concentrated than before the abatement system was installed. It is projected that in several years the aquifer will be largely decontaminated.

Althoff, W.F. and Reuter, G., "Hydrocarbon Spills Into the Ground Waters of New Jersey: Two Case Histories", Proceedings of the Conference on Oil and Hazardous Material Spills: Prevention, Control, Cleanup, Recovery, Disposal, 1979, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 151-159.

Ground water contamination from hydrocarbons has only recently been given the attention these incidents warrant. Dramatic events involving explosions, evacuations or injuries receive the greatest publicity. But smaller spills, inventory losses, accidents and other causes occur with almost routine frequency and pass unnoticed by the general public. Typically, an organized response is lacking, large quantities of hydrocarbons are released into the environment and damage to life, property and water supplies all too often result.

The number and importance of these cases have forced national recognition of the problem. In New Jersey, for example, a coordinated spill response program has existed for several years. The need is clear. In fiscal 1978, more than 1400 separate incidents were reported within the state. Although many of these proved to be unimportant, the totals are startling. The amount of material spilled in this period is estimated at 1.5 million gallons. More than 75% of this total, or more than 1.1 million gallons, involved petroleum compounds. Problems related to hydrocarbon spills into ground water are presented through two case histories. The first incident involved gasoline contamination of a major bedrock aquifer and is, perhaps, an extreme example of the frustrations associated with such spills. In contrast, a successful recovery in unconsolidated material provides an illustration of the clean-up process and the effectiveness of the geologist in spill response programs.

American Petroleum Institute, "Underground Spill Cleanup Manual", API Publication 1628, June 1980, Washington, D.C.

When gasoline, kerosene, or similar petroleum product is lost into the ground, its behavior and ultimate fate will depend on the hydrogeology, or underground water conditions. Although spills involving hazardous materials or large volumes of fluids should be handled by an experienced professional familiar with this kind of problem, an understanding of certain elements of geology and ground water hydrology can be useful to anyone dealing with an underground spill. This manual discusses these elements and certain spill cleanup methods.

American Petroleum Institute, "The Migration of Petroleum Products in Soil and Groundwater -- Principles and Countermeasures", Publication No. 4149, Dec. 1982, Washington, D.C.

This publication summarizes the methods being used by industry to control and prevent the migration of petroleum products in soil and ground water. The circumstances surrounding spills of petroleum products vary widely, and it is thus impossible to outline procedures that would be universally applicable. This publication does include, however, six case histories that describe procedures used in actual spills. These should serve as a useful guide to others who may encounter similar situations.

Anderson, D.C., Brown, K.W. and Green, J., "Organic Leachate Effects on the Permeability of Clay Liners", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1981, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 223-229.

Saturated conductivity or permeability is the primary laboratory measurement made on compacted clay soils to assess their suitability for use in constructing compacted clay liners for hazardous waste landfills or surface impoundments. The value obtained for the permeability is used to judge whether a compacted clay soil liner will prevent the movement of leachates into water bodies below or adjacent to the disposal facility. There is, however, little information available on the impact of organic fluids, likely to be placed in such confinements, on the permeability of the liner. Also, there has been no simple permeability test method developed that could be suitable for use with the range of possible waste fluids. Furthermore, a study evaluating the permeability of a range of typical clay soils with a spectrum of potential waste fluids would generate a valuable data base, useful for hazardous waste disposal permit applicants, writers and reviewers. Consequently this study was undertaken with the following objectives: (1) to construct from available information a delineation of the physical classes of fluid-bearing hazardous waste, the leachates they generate, and the predominant fluids in these leachates; (2) to develop a simple, inexpensive and rapid method for the comparative permeability testing of compacted clay soils, that would be suitable for use with a wide range of possible waste fluids; and (3) to evaluate the permeability of a range of typical clay soils to a spectrum of potential waste fluids.

Anderson, D.C. and Jones, S.G., "Clay Barrier-Leachate Interaction", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1983, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 154-160.

Interactions between clay barriers and leachate components may cause deterioration of the barrier's ability to contain the leachate. Two important dynamic clay barrier properties that may be affected by interactions with leachate are: effective pore volume, the pore space that transmits leachate percolating through a clay barrier; and permeability, the rate at which leachate percolates through a clay barrier at a given hydraulic gradient. Either a decrease in the effective pore volume at a constant permeability or an increase in the permeability of a clay barrier will result in an early appearance of leachate in the subsoil. Increased permeability of a barrier would result in an increased rate of leachate migration. A decrease in the volume of pores transmitting the leachate at a constant permeability would result in a decrease in the time it would take for the leachate to move through the barrier. A decrease in effective pore volume would occur if a clay barrier experienced shrinkage cracking. The leachate would preferentially move through the crack instead of through the whole clay barrier matrix. This would result in leachate breaching the clay barrier earlier than would be expected with a given permeability where the leachate moved uniformly through the clay barrier. Two of the most important potential failure mechanisms that involve barrier-leachate interaction are: dissolution and piping: dissolution of clay barrier constituents that bind particles together and the subsequent piping (movement of clay particles with the percolating leachate); and development of soil structure: pulling together of soil particles into aggregations of many particles resulting in the formation of large interaggregate pores. By understanding the mechanisms by which clay barriers fail, it may be possible to alter leachate to lessen its impact on the dynamic properties of the clay barriers. Knowing leachate components likely to affect barrier properties makes it possible to identify wastes that require pretreatment. Discussions of these two clay barrier failure mechanisms and the leachate components that may cause these failures are in this paper.

Arlotta, S.V., Jr., "The 'Envirowall Cut-Off' Vertical Barrier", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1983, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 191-194.

The migration of polluted ground water or leachate from contaminated sites or waste disposal areas, especially abandoned sites, is an environmental problem of national proportions. A new and unique concept called the "Envirowall Cut-Off" has been developed to construct a vertical, impermeable barrier to prevent this migration. "Envirowall Cut-Off" is a hybrid cut-off wall. It is constructed with high density polyethylene (HDPE) and sand backfill and is installed by using the slurry trench construction method. Once installed, a very low permeability, composite, vertical barrier is established with several unique engineering properties. The overall concept and construction methodology was demonstrated during a full scale construction test at a sanitary landfill in New Brunswick, New Jersey during the fall of 1982. The test was planned to demonstrate the feasibility of the techniques and materials used to construct the Envirowall Cut-Off under generally difficult (by design) conditions. The test also demonstrated the major advantages of the Envirowall Cut-Off over other types of cut-off wall construction.

Ayres, J.A., Barverik, M.J. and Lager, D.C., "The First EPA Superfund Cutoff Wall: Design and Specifications", Proceedings of the Third National Symposium on Aquifer Restoration and Ground Water Monitoring, 1983, National Water Well Association, Worthington, Ohio, pp. 13-22.

Rapidly moving organic solvents with concentrations in the tenth of a percent range forced fast-track installation of the first cutoff wall to be funded under EPA's Superfund Program. The wall, located in Nashua, New Hampshire, totaled nearly 20,000 M^2 in cross section, reached a maximum depth of 33 meters and surrounded a plume more than 80,000 M^3 in area. Excavation was accomplished using a modified Koehring backhoe capable of trenching in excess of 20 meters deep in combination with a 12-ton clam shell at depths more than 20 meters. The 1-meter wide slurry trench excavation was keyed into bedrock and backfilled with a soil/bentonite mixture. The entire excavation and backfilling process was completed in less than eight weeks. The project necessitated slurry wall specifications based on performance criteria due to warrantees on materials, workmanship and long-term performance required of the contractor. Performance criteria were established for hydraulic conductivity of the wall ($\leq 1x10^{-7}$ cm/sec); homogeneity of the backfill (no "windows"); long-term physical characteristics (cracking, shrinking, etc.); and the required depth of wall (top of bedrock). These performance criteria were further supplemented with minimum design standards to allow field control during construction. These included limits on the gradation of the backfill mix ($\geq$ 5 percent bentonite and $\geq$ 30 percent fines); the type of bentonite used (prequalified suppliers); quality control testing, and final verification testing. Field observation and quality control testing results obtained during construction indicate satisfactory installation of the cutoff wall, with respect to both excavation to top of bedrock and backfill characteristics. An average backfill hydraulic conductivity of $5x10^{-8}$ cm/sec with a maximum value of $4x10^{-7}$ cm/sec was attained during construction.

Bailey, L.R., "Control and Recovery of Acrylonitrile from the Ground Water Near a Residential Area: A Case History", Proceedings of the Conference on Oil and Hazardous Material Spills: Prevention, Control, Cleanup, Recovery, Disposal, 1979, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 175-177.

The threat to life, property, and the environment when hazardous materials are spilled on the land surface or into water dictate that corrective action be immediate and effective. The technology for handling such occurrences is advancing rapidly as a result of the experience gained and documented in recent years. However, when hazardous fluids enter the subsurface and/or ground water as results of spills, the problem takes on broader ramifications. The time and cost of remedial measures are necessarily increased. Each situation is unique and depends upon the geologic and hydrologic conditions at the spill site, but basic principles governing the movement of ground water are the dominant controls on movement of the hazardous fluid. This paper presents a case history of a recovery operation involving a spill of 34,000 gallons of acrylonitrile onto the land surface, and subsequently a large portion of the product which entered the ground water system beneath the residential community of Guilford, Indiana. The community of Guilford, with a population of 97 persons, is served by a public water utility; however, a few of these residents have wells.

Bareis, D.L., Cook, L.R. and Parks, G.A., "Safety Plan for Construction of Remedial Actions", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1983, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 280-284.

The USEPA and the Army Corps of Engineers have an interagency agreement for the Corps of Engineers to manage Superfund design and construction contracts and provide other technical assistance as requested in support of remedial action at hazardous waste sites. The Corps of Engineers primary responsibilities under this agreement take place when the USEPA has determined that Federal cleanup is appropriate (as opposed to remedial measures managed by states or private entities), and the USEPA has selected the remedial alternative to be implemented. The Corps then contracts for actual design and construction work and serves as the contract manager, reviewing designs and monitoring construction. A crucial part of successful remedial actions is insuring adequate safety and health precautions to protect both on-site employees and off-site populations. Construction of remedial measures often involves extensive physical disturbance of hazardous material; this creates hazards in addition to those normally encountered in site investigations. Another factor increasing the likelihood of a serious accident during construction activities involving hazardous waste is that construction workers often lack the specialized training given to site investigation teams. For these and other reasons, it became evident that existing safety manuals written to cover hazardous waste site investigations would not be directly applicable to construction activities. Therefore, the Corps of Engineers has developed guidelines for design contractors to prepare site-specific construction safety plans.

Barto, R.L. and Cleath, T.S., "Stringfellow: A Case History of Closure and Monitoring at a Hazardous Waste Disposal Site", Proceedings of the Second National Symposium on Aquifer Restoration and Ground Water Monitoring, 1982, National Water Well Association, Worthington, Ohio, pp. 323-339.

Leaking of hazardous wastes from the Stringfellow Class I Disposal Site located in a small canyon near Riverside, California, has had an adverse effect on the adjacent ground water basin. The site received approximately 32 million gallons of plating wastes, industrial solvents and DDT manufacturing residue between 1956 and 1972. Operations at the site were discontinued after observations of nearby surface-water contamination in 1969 and ground water contamination in 1972. The California State Water Resources Control Board retained the firm of James M. Montgomery Consulting Engineers, Inc. in 1976 to study site conditions and evaluate alternatives for closure of the site. Hydrogeologic conditions were investigated using exploratory drilling, trenching, seismic refraction, soil analyses and water quality analyses. Results of the exploration confirmed that pollutants had contaminated the local ground water basin for a distance of more than 4,000 feet downstream from the site. Excessive concentrations of inorganic and organic constituents within the plume were indicated by total dissolved solids concentrations in excess of 50,000 mg/l, pH levels frequently less than 3.5 and total organic halogen concentrations in excess of 700 mg/l. Corrective measures were designed to inhibit subsurface flow from the site and extract contaminated ground water downstream. Remedial measures included a clay barrier, subsurface grout curtain and interceptor wells. The effectiveness of these measures will be evaluated by systematic analyses of ground water samples from a network of monitoring wells. Disposal alternatives of contaminated ground water include full treatment, hauling, deep well injection, evaporation and partial treatment with ocean outfall.

Bilello, L.J. and Dybevick, M.H., "A Computer Model for Optimization of Groundwater Decontamination", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1983, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 248-252.

The design and cost estimating methods used in this paper allow two processes to be compared by specifying the waste stream flow rate and three parameters for each compound: partition coefficient, mass transfer coefficient and carbon adsorption capacity. For single-component waste streams, the most economical choice is usually clear; for waste streams with several contaminants for which there are varying response objectives, several alternatives, including combined technologies, may be evaluated quickly and on an equivalent basis to determine the most effective system or the most likely candidates for pilot study. In none of the cases evaluated for this paper were the economics of a combined system more favorable than a system using only one of the technologies.

Bituminous Coal Research, Inc., "Studies on Limestone Treatment of Acid Mine Drainage", Jan. 1970, Monroeville, Pennsylvania.

Four actual coal mine waters have been neutralized with limestone both on a batch scale and by utilizing a continuous flow apparatus. Variations in treatment procedure were necessary depending on the characteristics of the individual waters. A standardized test was established to evaluate the reactivity of the limestones. The following variables are of importance in evaluating limestones for coal mine water neutralization: (a) particle size, (b) Ca and Mg content, and (c) surface area. Ferrous iron oxidation has been accomplished with both synthetic and actual coal mine water at low pH in the presence of coal-derived activated carbon. Electrophoretic mobility studies on precipitates obtained by both lime and limestone neutralization of coal mine water yielded information which can be applied for more effective sludge removal. Magnetic sludges were prepared using two different iron-bearing waters. The conversion of precipitates to a magnetic form results in significant reductions in settled sludge volumes as well as increases in solids content. Data obtained in these studies indicate that the limestone process offers considerable promise for an improved lower cost method for treating several types of coal mine waters.

Bituminous Coal Research, Inc., "Studies of Limestone Treatment of Acid Mine Drainage: Part II", Dec. 1971, Monroeville, Pennsylvania.

Laboratory investigations have demonstrated the feasibility of using limestone in place of pure lime for treating acid mine drainage for the neutralization of acidity and removal of iron to acceptable limits. The process consists of: equalization; addition of pulverized limestone and mixing; aeration; slurry recirculation to the mixing area; sludge settling; and sludge dewatering and disposal. Total costs are given. Advantages and disadvantages of limestone over lime are also discussed.

Bixler, B., Hanson, B. and Langner, G., "Planning Superfund Remedial Actions", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1982, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 141-145.

The remedial action program is a key part of the Superfund mandate to clean up uncontrolled hazardous waste sites across the nation. The USEPA has developed a remedial planning process embodied in the National Contingency Plan (NCP) that ensures rapid, consistent, and rational decision-making on the appropriate extent of remedy at priority hazardous waste sites. In this paper, the authors review five elements of the remedial planning process: (1) the remedial action master plan, (2) remedial investigations, (3) feasibility studies, (4) selection of a remedial alternative, and (5) remedial design. For each of these activities, the authors discuss both the technical considerations and the procedural requirements for conducting and submitting a complete product. The emphasis in this paper is on remedial investigations and feasibility studies, which form the basis for determining the appropriate extent of remedy and the cost-effective remedial alternative at an uncontrolled hazardous waste site.

Blake, S.B. and Lewis, R.W., "Underground Oil Recovery", Proceedings of the Second National Symposium on Aquifer Restoration and Ground Water Monitoring, 1982, National Water Well Association, Worthington, Ohio, pp. 79-76.

When gasoline, kerosene or similar petroleum products are lost through leaks or spills to the ground, its behavior and ultimate fate become dependent on the local hydrogeologic conditions and physical properties of the petroleum products. If the soil in the spill areas has a high clay content and low permeability, the product will penetrate very slowly or not at all. However, a highly permeable sandy soil will allow rapid percolation of the product. In situations where oils are present and the local ground water is relatively shallow, the downward percolating products will tend to "accumulate" on the water table. The weight of the petroleum product will depress the ground water table surface and form an "oil pool" having a convex lens shape. With time, this mound will disperse laterally on the surface of the ground water. The rate of dispersion of any given product will depend on viscosity and gravity of the product; hydraulic properties of the aquifer; slope or gradient of the ground water table; and quantity of product that reaches the water table aquifer. For retrieval of fairly shallow accumulation of oil, techniques such as interception trenches, pumped trenches and French drain systems can be very effective. For recovery of products at depths greater than 15 feet, wells are generally the most cost-effective. In this instance techniques such as well points, single pumps with separators, and two-pump systems can be employed. In each oil recovery program the oil types and the hydrogeologic environment must be evaluated to determine which recovery method will be cost-effective and achieve the best results.

Blasland, W.V., Jr., et al., "The Fort Miller Site: Remedial Program for Securement of an Inactive Disposal Site Containing PCB's", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1981, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 215-222.

In September 1980, the General Electric Company and the New York State Department of Environmental Conservation (NYSDEC) signed the first major agreement in the nation in which a corporation agreed to pay for remedial action to clean up abandoned hazardous waste dump sites where, in the past, it had disposed of its industrial waste. The agreement involves remedial actions at seven land disposal sites in Saratoga, Rensselaer, and Washington Counties. General Electric has agreed to carry out all engineering studies and the necessary remedial action at four locations and has agreed to pay a percentage of the cost of the engineering studies and necessary remedial action at the three other sites. One of the sites included in the agreement is known as the Fort Miller Site.

It is located in the Town of Fort Edward, Washington County, approximately 7.5 miles south of Hudson Falls, New York. This paper summarizes the remedial program for the Fort Miller Site.

Blasland, W.V., Jr., et al., "Evaluation of Groundwater Hydraulics with Respect to Remedial Design", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1983, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 123-129.

In a hydrogeologic investigation of the Kingsbury landfill, ground water contamination attributed to discharges from the refuse was documented. In order to abate significant current and future releases or migration of hazardous wastes from the site, a remedial design involving in-place containment was developed. The remedial design consisted of a ground water cutoff wall keyed into a clay layer beneath the site and a low permeable cap installed over the refuse. The purpose of this in-place containment design is to effectively isolate the site from the hydrogeologic environment and thereby mitigate off-site migration of contaminated ground water. An analysis of the projected post-construction ground water hydraulics of the site was an integral part of the remediation design process and provided necessary documentation of the effectiveness of the proposed remediation to state regulatory officials. This analysis of the projected post-construction ground water hydraulics provided: an evaluation of the remedial design effectiveness in isolating the site from the hydrogeologic environment; an evaluation of the potential off-site migration of contaminated ground water and its potential impacts on the surrounding hydrogeologic environment; and information critical to the design and the remediation measures.

Bond, F.W., Cole, C.R. and Sanning, D., "Evaluation of Remedial Action Alternatives -- Demonstration/Application of Groundwater Modeling Technology", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1982, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 118-123.

The LaBounty landfill was an active chemical waste disposal site from 1953 to 1977. During this period, it is estimated that over 181,000 m^3 of chemical wastes were disposed in this 4.86 ha site located in the flood plain of the Cedar River in Charles City, Iowa. Compounds that are known to have been dumped in significant quantities include arsenic, orthonitroaniline (ONA), 1,1,2-Trichloroethane (TCE), phenols. and nitrobenzene. Disposal ceased in December 1977 following the discovery that wastes from the site were entering the river. Since that discovery, the LaBounty landfill has been under intensive investigation. One aspect of these investigations was the ground water modeling effort described in this paper. The overall objective of this modeling effort was to demonstrate the use of modeling technology for evaluating the effectiveness of existing and proposed remedial action alternatives at the site. The primary emphasis of the project was on technology demonstration which included: modeling of the ground water system and prediction of the movement of contaminants; development of criteria to determine which water sources impacted by the site would require remedial action and the level of action necessary to insure risks are at acceptable risk levels; and the evaluation of the costs and effectiveness of various remedial action alternatives.

Boutwell, S.H., et al., "A Model Based Methodology for Remedial Action Assessment at Hazardous Waste Sites", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1983, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 135-139.

In the past, selection and design of remedial actions for uncontrolled hazardous waste sites has largely been accomplished through field data collection, simple analyses and engineering judgment. Such approaches are generally satisfactory for more sites. There is a subset of sites, however, where conditions are so complex that simple analyses may not provide enough guidance to allow for the proper selection and design of remedial actions. Given the high economic costs to government and industry associated with site cleanup combined with the future societal cost of inadequate actions, it is important that effective, economical actions be chosen. Thus, there is a need for a remedial action assessment methodology which is flexible enough to provide the appropriate level of analysis and accurate enough to provide confidence in the decisions made. It is clear from experience to date that two levels of sophistication are needed in hazardous waste site and remedial action assessments: (1) simplified, "desk-top" methods (e.g., nomographs, analytical equations and hand-held calculator programs) for use where resources such as data, time, money and user expertise are limited and, (2) comprehensive numerical models for use on complex sites that will require costly remedial actions. Consequently, a methodology is being developed that provides: (1) a comprehensive modeling capability by interfacing sophisticated models for the three hydrologic zones, (2) flexibility by incorporating simplified, "desk top" methods which require limited resources in their application and (3) guidance on when to apply each method. In this paper the authors focus on the first issue: the selection and interfacing of sophisticated models.

Bradley, E., "Trichloroethylene in the Ground-Water Supply of Pease Air Force Base, Portsmouth, New Hampshire", Water Resources Investigations Open-File Report 80-557, 1980, U.S. Geological Survey, Boston, Massachusetts.

TCE (trichloroethylene) in concentrations that may be hazardous to health occurs in the water of an ice-contact largely sand and gravel aquifer (called the main aquifer) underlying much of the PAFB (Pease Air Force Base). In 1977 and 1978, the highest TCE concentration was found surrounding the most productive well, Haven well. Large quantities of TCE were used for degreasing between 1955 and 1965 and, so far as is known, TCE was used extensively up until 1973. Data on how, where, and when TCE got into the aquifer are lacking, but geochemical evidence and TCE analyses show a strong relation between the high TCE concentrations near Haven well and the extensive storm-drain system that underlies the parking apron and runway. The drains help recycle some of the TCE-contaminated ground water from the Haven well area. This study locates TCE contamination in the main PAFB aquifer and discusses three possible water-use alternatives: (1) abandonment of Haven well, (2) treatment of Haven well water to remove TCE, and (3) treatment of a portion of Haven well water for domestic consumption and use of the remainder for nondomestic uses. Continued use of the Haven well, with treatment of all or part of its yield for TCE removal, is advantageous, both because the Haven well is a high-yield source of water and because cessation of pumping from it might allow TCE-contaminated ground water to move downgradient (southward), endangering other wells.

Brown, K.W. and Anderson, D., "Effect of Organic Chemicals on Clay Liner Permeability: A Review of the Literature", *Proceedings of the Sixth Annual Research Symposium on Disposal of Hazardous Waste*, 1980, U.S. Environmental Protection Agency, Cincinnati, Ohio, pp. 123-134.

Permeability is the primary criteria for evaluating the suitability of clay soils for lining of waste impoundments. A review of available information has revealed the near-complete lack of knowledge about the possible impact typical waste impoundment contents have on the permeability of clay liners. The aims of this review have been to develop a list of organic chemicals found in waste impoundments; develop a list of clay minerals used to line impoundments, and review possible mechanisms for the failure of these liners.

Brunotts, V.A., et al., "Cost Effective Treatment of Priority Pollutant Compounds with Granular Activated Carbon", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1983, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 209-216.

> Carbon adsorption has played a key role in many wastewater treatment installations in helping them meet their treatment objectives. Based on a decade of experience, the authors discuss the effectiveness of activated carbon for the removal of a variety of pollutants when utilized for treatment in a representative sample of 17 industrial projects. Data from 29 ground water and spill control applications is presented to demonstrate the efficiency of carbon adsorption in this area of treatment. The cost effectiveness of carbon adsorption, while accomplishing high removal efficiencies, is also discussed. In light of new treatment challenges (ground water contamination, for example) and future comprehensive priority pollutant regulations, Calgon has developed a new technology for analyzing contaminated water quickly. The newly developed Accelerated Column Test (ACT) has several advantages over conventional test methods in addition to the speed with which it can be run. The advantages of the ACT are discussed along with an example of how the ACT correlates to current testing methods.

Brunsing, T.P. and Cleary, M., "Isolation of Contaminated Ground Water by Slurry-Induced Ground Displacement", Proceedings of the Third National Symposium on Aquifer Restoration and Ground Water Monitoring, 1983, National Water Well Association, Worthington, Ohio, pp. 28-38.

> Ground water supplies throughout the U.S. are threatened by leaching and migration of contaminants from numerous sources including solid, chemical and hazardous waste sites. Complete isolation of these sources and their corresponding high concentration migrating plumes is a major step in mitigating the danger of ground water contamination and is often a cost effective step in the remedial cleanup process. A technique referred to as "block displacement" has been developed for complete isolation of large tracts of contaminated ground. A full-scale demonstration was recently conducted on a 50,000 cubic foot block of unconsolidated soil. The block displacement technique places an impermeable barrier around and beneath the contaminated zone. In the process, the ground is physically displaced upward by multiple well injection of a barrier material in a slurry state. The block displacement process is composed of separate bottom barrier and perimeter barrier construction processes, each of which is described in detail. The interaction between perimeter and bottom construction processes is explained. Application guidelines including a "mini-displacement" test are outlined. A cost

comparison with other cleanup methodologies and additional cost considerations of this system are also discussed.

Brunsing, T.P. and Grube, W.E., Jr., "A Block Displacement Technique to Isolate Uncontrolled Hazardous Waste Sites", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1982, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 249-253.

A technique for complete in situ isolation of uncontrolled hazardous waste sites has been developed. This technique is intended to emplace a seal at low cost around the sides as well as underneath contaminated ground. Demonstration of the Block Displacement Method (BDM) was conducted over a four month period adjacent to the Whitehouse Oil Pits site in Whitehouse, Florida. The purpose of the demonstration project was to add this technique to the list of available construction technologies applicable to chemical waste remedial action by: demonstrating the BDM in the geologic conditions of an existing chemical waste site; developing BDM specifications for "A User's Guide for Evaluating Remedial Action Technologies"; evaluating the applicability of the BDM to existing site geologic/hydrologic conditions; and establishing BDM implementation procedures for remedial action designers and contractors.

Burt, E.M., "The Use, Abuse and Recovery of a Glacial Aquifer", Ground Water, Vol. 10, No. 1, Jan.-Feb. 1972, pp. 65-72.

The inter-relationships between an industrial plant and a shallow sand aquifer of glacial origin are described. These relationships include industrial and potable water supplies, industrial and human waste water disposal systems, the hydraulics of the pollution of the ground water aquifer and the types of corrective actions taken to re-establish the wise use of the ground-water resource. Also reviewed are the ground water movement-quality relationship, well designs, method of drilling, well redevelopment and ground water recharge.

Cavalli, N.J., Arlotta, S.V. and Druback, G., "Subsurface Pollution Containment with the 'Envirowall' Vertical Cutoff Barrier", Proceedings of the Third National Symposium on Aquifer Restoration and Ground Water Monitoring, 1983, National Water Well Association, Worthington, Ohio, pp. 23-27.

This paper presents a new and unique concept to construct a vertical impermeable barrier to prevent the migration of polluted ground water or leachate from a contaminated site or waste disposal area. Developed by the ICOS Corporation of America, "Envirowall" is a hybrid cutoff wall. It is constructed with high density polyethylene (HDPE) and sand backfill, and it is installed using the slurry trench construction method. Once installed, a very low permeability, composite, vertical barrier is established with several unique engineering properties. These properties and engineering analyses are described in the paper. The "Envirowall" essentially functions as a cutoff wall with redundant features for controlling horizontal seepage. The HDPE is used to form an envelope which lines the walls of an excavated trench. The bentonite slurry used during construction keeps the trench stable for placement of the HDPE and sand backfill and also forms a filter cake on the walls of the trench. This filter cake further decreases the permeability of the composite in-place barrier. The sand backfill, besides serving as ballast, provides an internal, porous medium for monitoring seepage and, if necessary, withdrawal of intruding pollutants.

Depending on site stratigraphy, cutoff walls are often keyed into an underlying soil stratum of low permeability to effectively seal off the horizontal migration of contaminated ground water. This is often done at landfill sites or hazardous waste disposal sites as a remedial measure. The "Envirowall" has several advantageous features when used in this capacity. Recent research indicates that changes in permeability of clay soil often used for constructing liners and vertical barriers can be a major concern upon exposure to certain chemicals and subsequent permeation. The HDPE envelope provides a stable, low permeable (10^{-12} cm/sec) membrane and, when installed in the trench, it provides improved resistance to permeation and low overall permeability for the "Envirowall" system. The slurry trench construction method allows installation of the "Envirowall" in areas with difficult site conditions and to relatively deep elevations. An important component of the "Envirowall" is the sand backfill. As the HDPE envelope is placed in its trench, it is backfilled with sand and water to submerge it and to help the HDPE conform to the shape of the trench. The sand provides a medium in which monitoring wells may be placed to monitor water quality within the wall on a long-term basis. If leakage is ever noted by detection of contamination in a monitoring well, the porous sand medium can be pumped to evacuate and control the contaminated water and prevent further migration.

A full-scale construction test project of the "Envirowall" was performed at an existing sanitary landfill in New Jersey in the fall of 1982, to demonstrate the overall construction procedure for fabricating the HDPE liner and placing it into a trench filled with slurry by backfilling with sand. The project was conducted in three phases: 1) the excavation of a triangular shaped trench filled with the bentonite slurry mixture through the landfill waste, 2) the cutting and seaming of HDPE material to form an envelope with the prescribed geometry, and 3) the placement of this HDPE envelope in the trench and subsequent backfilling with sand and water. The success of the operation under difficult conditions proved that the theory and construction concept of the "Envirowall" can be utilized to construct a composite cutoff wall. Much information was gained for use in future applications.

Chaffee, W.T. and Weimar, R.A., "Remedial Programs for Ground-Water Supplies Contaminated by Gasoline", Proceedings of the Third National Symposium on Aquifer Restoration and Ground Water Monitoring, 1983, National Water Well Association, Worthington, Ohio, pp. 39-46.

This paper describes programs for investigating and cleaning ground water supplies contaminated by gasoline. Two case histories where leaks from buried gasoline storage tanks at service stations impacted public and private drinking water supplies are discussed. The procedures taken to investigate the gasoline contamination, including installation of monitoring wells, methods of gasoline lens detection and contaminant plume detection are described. In describing techniques for detecting spills, a discussion of contaminant transport and the geophysical phenomena involved with gasoline movement is provided. Emphasis is placed on gasoline movement above the ground water surface in the capillary fringe. Various methods used in detecting contaminant plumes are discussed and relate to a specific case history. Final cleanup plans are described for both sites. The criteria used for assessment of remedial alternatives are similar for both sites. However, the final cleanup techniques and schedules are different. Methods for on-site gasoline removal and treatment are discussed in detail. In one case, the final cleanup method has been approved by local and state regulatory authorities and is in the final design stage. This system is composed primarily of a recirculation cell treatment technique with air stripping, vapor phase granular activated carbon (GAC) treatment and liquid phase GAC treatment for the hydrocarbon contamination in the recirculation cell water. A computer model designed for use on an interactive graphics computer system was developed to aid in the recirculation cell analysis.

Clark, T.P., "Survey of Ground Water Protection Methods for Illinois Landfills", Ground Water, Vol. 13, No. 4, July-Aug. 1975, pp. 321-331.

This paper summarizes the experience in Illinois of development of a rational program for protection of the State's ground and surface water from the indiscriminant disposal of solid wastes. Classes of solid waste sites recognized in the State and their position in terms of the hydrogeologic environment are presented. Means of controlling landfill leachate, either by natural renovation in subsurface materials or by engineered collection and treatment are discussed. Examples are presented which illustrate the in-field implementation of protective systems and monitoring devices for ground water in Illinois, which should be generally applicable to other areas of the country of similar geology and climate.

Cochran, S.R., et al., "Survey and Case Study Investigation of Remedial Actions at Uncontrolled Hazardous Waste Sites", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1982, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 131-135.

With the passage of the Comprehensive Environmental Response, Compensation, and Liability Act (Superfund) and the release of the National Contingency Plan, the USEPA has developed a systematic methodology for assigning liability and conducting remedial actions at uncontrolled hazardous waste management facilities. It is clear from past experiences such as Love Canal that short term and long term environmental and health related hazards exist when inadequate technologies are used during the handling and disposal of hazardous materials. Because new remediation techniques are continually evolving and known technologies are constantly being retrofitted and adapted for remedial actions use, the alternatives available for cleanup are continuing to expand. In order to assess the effectiveness and limitations of these remedial actions techniques, USEPA is conducting case study examinations of these technologies which have been employed in field situations.

Cohen, R.M. and Miller, W.J., "Use of Analytical Models for Evaluating Corrective Actions at Hazardous Waste Disposal Facilities", Proceedings of the Third National Symposium on Aquifer Restoration and Ground Water Monitoring, 1983, National Water Well Association, Worthington, Ohio, pp. 85-97.

Many land-based hazardous waste disposal facilities have been cited by the U.S. Environmental Protection Agency (EPA) as endangering human health and the environment because they are leaking hazardous contaminants into ground water. The operators of these facilities are being required to prevent contaminant migration and to institute measures to clean up contaminated ground water beyond a specified distance from the facility (i.e., the compliance point which is dictated by the EPA in the facility operating permit). As such, engineering solutions will be implemented as corrective actions to control contaminant migration and to remove contaminants in ground water beyond the compliance point. These measures will often be large scale and costly. Therefore, it is economically advantageous to evaluate the effectiveness of corrective actions prior to their implementation. The most common corrective actions include the installation of slurry cutoff walls, French drains, clay caps and interceptor wells. During the design phase of corrective actions, analytical models allow a first-cut evaluation of the effectiveness of a particular measure or a combination of measures. To exemplify this approach, a variety of analytical solutions applied to specific corrective action scenarios are presented with emphasis on their critical assumptions and limitations.

Cole, C.R. and McKown, G.L., "The Use of Mathematical Models to Assess and Design Remedial Action for Chemical Waste Sites", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1981, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 306-312.

It is estimated that there may be 30,000-50,000 old disposal sites and sites contaminated from spills in the United States, of which 1,000-2,000 are sufficiently contaminated to pose a hazard to the public. Restoration costs are likely to exceed $1,000,000 per site. Faced with the complexity and high costs of addressing such a large number of sites, it is clear that formalized methods are required to expedite the restoration process and identify the most cost-effective means of site remedial response. This paper describes a methodology which utilizes mathematical models describing fluid flow and contaminant transport. These constructs have been developed over a period of nearly two decades and employed to solve a variety of surface and ground water contamination problems. They offer the ability to organize, interpret and better understand what is presently occurring, and in addition, provide the ability to predict what will occur in the foreseeable future. These capabilities are of particular value in designing remedial action since, through the use of these tools, one can: (1) determine when a specific site is sufficiently characterized and understood such that when implemented the selected remediation program will be effective; (2) allow one to design a cost effective site characterization and data gathering effort; (3) rapidly and cost effectively assess a wide variety of remedial options without moving any dirt; and (4) design a cost effective site surveillance and monitoring plan which will maximize the ability to detect any deviation from the remediation plan.

Continental Oil Company, "Microbiological Treatment of Acid Mine Drainage Waters", Sept. 1971, Ponca City, Oklahoma.

The purpose of the study was to determine if the abilities of certain bacteria to oxidize ferrous iron or to convert sulfate to hydrogen sulfide could be applied to the neutralization and subsequent removal of iron from difficult-to-treat mine drainage waters. If one or both of these concepts could be successfully utilized, the expense of adequately treating these types of problem waters might be significantly reduced. Laboratory studies demonstrated that both pure cultures and fresh field cultures of acidophilic iron bacteria could readily oxidize ferrous iron in both synthetic and natural acid mine drainage waters. Approximate requirements of oxygen, carbon dioxide, nitrogen and phosphorus by the iron bacteria were established. Limestone neutralizations of partially oxidized acid mine waters were conducted. Although sulfate-reducing bacteria were isolated, attempts to grow the cultures or produce hydrogen sulfide at pH values below 5.5 were unsuccessful.

Cooper, J.W. and Shultz, D.W., "Development and Demonstration of Systems to Retrofit Existing Liquid Surface Impoundment Facilities with Synthetic Membrane", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1982, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 244-248.

Surface impoundment facilities such as pits, ponds, and lagoons are used extensively throughout the United States to store, treat and dispose of hazardous wastes. These impoundments usually are designed to contain fluids, utilizing native materials or liners and in the past, many were constructed with little concern for preventing seepage from the facility. In fact, many such facilities were designed to seep water into the ground as a means of disposal. Unfortunately, many of these facilities are presently causing ground water contamination problems. With the establishment of regulations passed under authority of the Resource Conservation and Recovery Act (RCRA) legislation, retrofitting in-service disposal and treatment impounds may be required to prevent continued seepage. Retrofitting with impermeable liners may accomplish this objective. Liners may also be required to protect against wind and water erosion, another objective of RCRA regulation requirements. Retrofitting an in-service impoundment with a flexible membrane liner generally implies the emplacement of liner material on the bottom and sides of a facility to mitigate leakage without removing any in situ fluid (hazardous material) in the impoundment. Such action may be desirable as a temporary measure, while a new impoundment is constructed, or as a permanent step to upgrade an untrustworthy facility. In this paper, the authors report on an ongoing project that Southwest Research Institute is conducting for the USEPA, for the development and demonstration of systems to retrofit existing liquid surface impoundment facilities with synthetic membrane liners.

Crystal, R.M. and Heeley, R.W., "Comprehensive Aquifer Evaluation and Land-Use Planning for Aquifer Restoration and Protection in Acton, Massachusetts", Proceedings of the Third National Symposium on Aquifer Restoration and Ground Water Monitoring, 1983, National Water Well Association, Worthington, Ohio, pp. 175-185.

A crucial, but often neglected, part of aquifer restoration programs should be to ensure that contamination incidents are not repeated. Acton, Massachusetts, moved to protect its ground water after losing 40 percent of its water supply in 1978 due to organic chemical pollution by a W.R. Grace chemical plant. Grace signed consent decrees with EPA and the town to pay for restoration of the Sinking Pond aquifer, to be coordinated with townwide, town-financed planning and geohydrologic studies. Acton engaged Lycott Environmental Research to conduct a two-part study: a geohydrologic analysis to evaluate ground water quality and quantity and identify alternative supplies, and a planning assessment to develop regulations and actions to protect water supply. The geohydrologic analysis provided an extensive data base. Eight geohydrologic maps were compiled: data locations, bedrock topography, hydrologic materials, surficial geology, saturated thickness, transmissivity, water table elevation and water quality hazards. Twent-five monitoring wells were installed and sampled, and a long-term monitoring program was developed. Potential well sites were identified. The planning analysis had three key steps: mapping the most important areas for protection, conducting a modeling analysis to determine if current and saturation land use would significantly elevate ground water nitrate levels, and revising zoning development regulations and management actions. An aquifer protection map was prepared for use in a zoning overlay district defining restricted uses. Engineering requirements and performance standards covering hazardous materials, fuel storage and solid and industrial waste disposal were proposed. Nitrate modeling indicated that the federal 10 mg/l standard would be exceeded in several aquifers at saturation development, but recommended zoning changes could meet the standard. Acton is currently implementing the plan, giving priority to rezoning to restrict industry in the Sinking Pond aquifer so it can be used for water supply after restoration.

D'Appolonia, D.J., "Slurry Trench Cutoff Walls for Hazardous Waste Isolation", undated, Engineered Construction International, Inc., Pittsburgh, Pennsylvania.

Slurry trench cut-off walls have been used extensively in the past decade as foundation and embankment cut-offs for water retaining structures and to control seepage into excavations. More recently, slurry trench cut-offs have been successfully employed to prevent underground seepage of liquid wastes and to isolate leachate from solid wastes from contaminating ground water. Advances in technology have enabled construction of exceptionally low permeability cut-offs which remain stable in a contaminated environment and resistant to chemical attack by the waste being contained. The Resource Conservation and Recovery Act has resulted in stringent requirements for new disposal areas and imposes new requirements for upgrading isolation of existing and abandoned landfills. In many cases, slurry trench construction is the only practical means of isolating existing waste disposal areas short of excavating and transporting in-place waste materials to new disposal sites. This paper reviews the various systems for isolating hazardous waste materials and points out the geological conditions where slurry trench construction is most applicable. The important elements of slurry trench design and investigation necessary to insure an effective waste isolation barrier are reviewed. These include mainly the connection between the slurry trench cut-off and the underlying aquaclude and the design of the slurry trench backfill material itself. Important considerations include not only the permeability of the isolation barrier, but also the long-term effects on the engineering properties of the barrier resulting from contact with or leaching by the contained hazardous waste material.

Dobbs, R.A. and Cohen, J.M., "Carbon Adsorption Isotherms for Toxic Organics", EPA-600/8-80-023, Apr. 1980, U.S. Environmental Protection Agency, Cincinnati, Ohio.

An experimental protocol for measuring the activated carbon adsorption isotherm was developed and applied to a wide range of organic compounds. Methods for treatment of the isotherm data and a standard format for presentation of results are shown. In the early phase of the study selection of compounds for testing in the experimental program presented a formidable task. Initial selections were based on the following criteria: (1) annual quantity produced, (2) critical concentration required to produce an adverse environmental effect, (3) probability of occurrence in water or wastewater, (4) persistence in the water environment, and (5) solubility. During the course of the study the Occupational Safety and Health Administration's (OSHA) list of regulated carcinogens and the U.S. Environmental Protection Agency's Consent Decree list of priority pollutants were developed. These compounds were added to those previously selected for the experimental phase of the study.

Dowiak, M.J., et al., "Selection, Installation, and Post-Closure Monitoring of a Low Permeability Cover Over a Hazardous Waste Disposal Facility", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1982, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 187-190.

A closure plan, recently designed and implemented for a hazardous waste disposal facility, included the installation of a low-permeability cover over the wastes. This facility, located in western Pennsylvania, consisted of a lime neutralization plant and a 26-acre sludge impoundment. The facility started operations prior to the existence of strict hazardous waste disposal regulations and was not constructed with a liner system to protect ground water. As part of the closure requirements of the Pennsylvania Department of Environmental Resources (PADER), a low-permeability cover as well as a leachate collection and treatment system had to be installed. In addition, the facility owner is responsible for monitoring aquifers beneath the site to determine changes in water quality and the effectiveness of the liner. Presented in this paper are the hydrogeologic conditions, the considerations that went into cover selection and design, the cover installation procedure and cost, and the ground water monitoring plan.

Duffala, D.S. and MacRoberts, P.B., "Implementation of Remedial Actions at Abandoned Hazardous Waste Disposal Sites", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1982, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 289-290.

In this paper, the authors describe current efforts to study, design, and implement remedial actions at abandoned hazardous waste disposal sites in USEPA Regions VI through X. They also discuss the legislative background and enabling authorities to provide such remedial activities, issues related to the objectives of Superfund, and investigations and feasibility studies at an abandoned site.

Ehrenfeld, J. and Bass, J., "Handbook for Evaluating Remedial Action Technology Plans", EPA-600/2-83-076, Aug. 1983, U.S. Environmental Protection Agency, Cincinnati, Ohio.

There are four major exposure pathways for uncontrolled hazardous waste disposal sites: (1) ground water/leachate; (2) surface water; (3) contaminated soils and residual waste; and (4) air. Remedial action technologies are designed to reduce exposure to humans and the environment to acceptable levels by either containing hazardous materials in place or removing the intrinsic hazard by decontaminating or physically removing the hazardous substances. This report contains information on over 50 remedial action technologies. A brief description, status, factors for determining feasibility and reliability, principal data requirements, and basic information for cost review are given for each technology. In addition a general discussion of the major pathways and associated remedial approaches and of monitoring techniques has been included.

Ehrlich, G.G., et al., "Degradation of Phenolic Contaminants in Ground Water by Anaerobic Bacteria: St. Louis Park, Minnesota", Ground Water, Vol. 20, No. 6, Nov.-Dec. 1982, pp. 703-710.

Coal-tar derivatives from a coal-tar distillation and wood-treating plant that operated from 1981 to 1972 at St. Louis Park, Minnesota contaminated the near-surface ground water. Solutions of phenolic compounds and a water-immiscible mixture of polynuclear aromatic compounds accumulated in wetlands near the plant site and entered the aquifer. The concentration of phenolic compounds in the aqueous phase under the wetlands is about 30 mg/l but decreases to less than 0.2 mg/l at a distance of 430 m immediately downgradient from the source. Concentrations of naphthalene (the predominant polynuclear compound in the ground water) and sodium (selected as a conservative tracer) range from about 20 mg/l and 430 mg/l in the aqueous phase at the source to about 2 mg/l and 120 mg/l at 430 m downgradient, respectively. Phenolic compounds and naphthalene are disappearing faster than expected if only dilution were occurring. Sorption of phenolic compounds on aquifer sediments is negligible but naphthalene is slightly sorbed. Anaerobic biodegradation of phenolic compounds is primarily responsible for the observed attenuation. Methane was found only in water samples from the contaminated zone (2-20 mg/l). Methane-producing bacteria were found only in water from the contaminated zone. Methane was produced in laboratory cultures of contaminated water inoculated with bacteria from the contaminated zone. Evidence for anaerobic biodegradation of naphthalene under either field or laboratory conditions was not obtained.

Emig, D.K., "The Department of Defense's Installation Restoration Program", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1982, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 128-130.

The Department of Defense (DoD) began its Installation Restoration (IR) program in 1975. The IR program is a comprehensive program to identify and evaluate past DoD hazardous waste disposal sites on DoD installations, and to control the migration of contamination resulting from such operations. The IR program also is applicable to property that is excess to DoD requirements and which might be made available for other public or private use. The objectives of the DoD restoration program are: to identify and evaluate past hazardous material disposal sites on DoD facilities, to control contamination migration, and hazards to health and welfare; and to review and decontaminate as necessary land and facilities excess to DoD's mission. DoD has required that the military departments and the Defense Logistics Agency establish and operate installation restoration programs, and complete records searches at every installation listed on their priority lists by the end of FY 1985. They have also been required to develop and maintain a priority list of contaminated installations and facilities requiring remedial action. In the IR program, priority is given to control of migrating contamination that may pose a threat to the public health and welfare of surrounding communities or to on-post personnel.

Emrich, G.H. and Beck, W.W., "Top-Sealing to Minimize Leachate Generation: Case Study of the Windham, Connecticut Landfill", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1980, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 135-140.

It has been estimated that 15,000 landfills are now operating in the United States. The Resource Conservation and Recovery Act (RCRA) of 1976 requires that landfills not meeting criteria for solid waste disposal facilities and practices be closed. There are numerous remedial action alternatives that can be used during or after the closure of landfills and dumps. Some of these are passive requiring little or no maintenance after being emplaced. Others are active and require a continuing input of manpower and/or electricity. Techniques for the reduction or elimination of water movement into landfills may be considered in five categories: (1) surface water control; (2) passive ground water management; (3) active ground water or plume management; (4) chemical immobilization of wastes; and (5) excavation and reburial.

Emrich, G.H., Beck, W.W. and Tolman, A.L., "Top-Sealing to Minimize Leachate Generation", undated, SMC-Martin, King of Prussia, Pennsylvania.

After evaluation of more than 400 landfills, the Windham, CT landfill was selected for the implementation of a remedial action program. For the present study, SMC-Martin drilled additional wells to determine the thickness of the refuse, the depth of the water table under the landfill, the depth to bedrock and ground water quality. An electrical resistivity survey was conducted in order to define the areal extent of the leachate plume. Remedial action alternatives evaluated for this site included regrading, revegetation, surface sealing, ground water cutoff, and plume management. The first three methods proved to be the most cost effective. Suction lysimeters, pan lysimeters, staff gages, and monitoring wells were installed to determine water movement into the landfill and the effectiveness of the remedial measures. During the summer of 1979, a remedial program was implemented. The site was regraded, gas vents were installed, and 15 cm (6 in) of sand and gravel were emplaced with an additional layer of 10 cm (4 in) of fine-grained sand washings to protect the surface seal. A 20-mil PVC membrane seal was emplaced and covered with 46 cm (18 in) of sand and gravel into which composted sewage sludge and leaves were disced. Revegetation will be accomplished by hydroseeding with a mixture of grasses. Monitoring is being conducted to determine the effectiveness of the membrane seal.

Environmental Research and Application, Inc., "Concentrated Mine Drainage Disposal into Sewage Treatment Systems", Sept. 1971, Wilton, Connecticut.

Studies were undertaken on a small scale to determine the effect liquid waste artificial iron-rich acid brines had on municipal sewage treatment processes. The brines were devised to simulate concentrates from treatment of acid mine drainage. At very high concentrations, the brines neutralized with lime give virtually complete removal of phosphate from primary effluent, activated sludge effluent, or anaerobic sludge digester decantate. The cost of the iron-rich acid brine produced from acid mine drainage by the reverse osmosis membrane treatment is estimated. Costs of transportation by rail, truck, and pipeline are also shown.

Ess, T.H. and Shih, C.S., "Multiattribute Decision Making for Remedial Action at Hazardous Waste Sites", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1981, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 230-237.

Many modern technology related problems, especially those involving man created risks, are extremely complex and uncertain. Large volumes of data and multiple conflicting objectives lead to the requirement for incorporating subjective judgments into the decision process. If the existence of adversary positions (i.e., a politicized conflict) is involved, then something other than just intuition must be relied on to find generally acceptable solutions. The problem area of hazardous waste management is just such a situation. Multiattribute decision analysis is an apparently effective tool for this type of problem. If is highly flexible, incorporates methods to handle uncertainty, multiple objectives, etc. and is a well developed technique. However, it is not without faults. The most glaring is its inability to properly treat the public's subjective perception of risk. In addition, conventional decision analysis can become extremely cumbersome if the problem being analyzed is complex and no readily available means of tree "pruning" exists.

An obvious answer to this is to somehow integrate multiattribute decision analysis with a quantitative risk assessment technique which addresses public perception. The basic steps entailed in such a unified approach are delineated below:

(1) Construct a decision tree for the potential course of remedial actions.

(2) Complete a detailed risk analysis.

  a. Determine the objective risk of each decision branch. (Note: According to some authorities this would be termed modeled risk.)

  b. Determine the appropriate risk referents.

  c. Use an objective risk vs. risk referent comparison to determine if a decision branch requires modification or should be eliminated from consideration (i.e., pruned).

(3) Conduct a sensitivity analysis of the risk comparison to determine which branches are only "marginally" acceptable.

(4) Complete the multiattribute decision analysis with the pruned tree.

(5) Conduct a sensitivity analysis of the "solution".

This paper explores this integrated technique in more detail.

Evans, J.C. and Fang, H.Y., "Geotechnical Aspects of the Design and Construction of Waste Containment Systems", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1982, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 175-182.

Disposal of hazardous and toxic wastes in the subsurface environment has resulted in the widespread application of geotechnology to the design and construction of waste containment systems. The adaptation of conventional passive ground water and surface water barriers to waste containment requires certain special considerations. In this paper, the authors present a systematic engineering approach to passive containment alternatives designed to mitigate contaminant migration. Certain design and construction aspects of the application of geotechnology to these systems are also presented. The three major passive containment components which are covered in detail are: 1) top seals, including covers of native clay, processed clay and polymeric (synthetic) membranes, 2) barrier walls, including soil-bentonite slurry trench walls, cement-bentonite slurry trench walls, and vibrating beam cutoff walls, and 3) bottom seals, including liners of native clay, processed clay, and polymeric membranes. Emphasis is placed on the geotechnical aspects of design and construction practices of waste encapsulation, including advantages and limitations. The functions of each of these components are defined. The design process is then detailed with emphasis on the difference between conventional applications versus waste containment applications (for example, slurry trench cutoff walls for waste containment must incorporate additional considerations in design as compared to their use to control ground water during excavation).

Many site investigations are conducted by hydrogeologists to obtain data for assessment of contaminant migration. Subsequently, waste containment systems may be engineered as part of a pollution abatement program. It is essential that the geotechnical engineering information required be obtained during the site investigation phase in order to allow for a thorough, yet cost-effective, engineering design. In this paper, the authors present a guide to the engineering data required to enable geologists to plan and conduct subsurface investigations which will provide geotechnical as well as hydrogeological data for design.

Fabolini, F. and Rice, P.A., "Biological Treatment of Acid Mine Water", July 1971, Syracuse University, Syracuse, New York.

A strain of Desulfovibrio Desulfuricans was used to test the feasibility of treating acid mine water biologically. Sulfate reduction rates were measured with lactate media at different temperatures, influent pH, and sulfate concentrations in batch and continuous reactors. Among the several additional organic substrates tested, digester sludge appears to be the most attractive because of its low cost and its neutralizing properties. Sulfate reduction in mixtures of acid mine water and digester sludge were demonstrated in a semi-continuous reactor and the sulfate reduction rates were measured. The controlling factors of sulfate reduction are discussed.

Fitzwater, P.L., Brassow, C.L. and Fetter, C.W., "Assessment of Ground Water Contamination and Remedial Action for a Hazardous Waste Facility in the Gulf Coast", Proceedings of the Third National Symposium on Aquifer Restoration and Ground Water Monitoring, 1983, National Water Well Association, Worthington, Ohio, pp. 135-141.

This paper outlines the contamination assessment and closure plan for a solid waste pit near Houston, Texas. The hydrogeologic investigation was initiated with a review of the literature and study of aerial photographs. This was followed by soil test borings and laboratory testing, installation of piezometers, and in situ testing of the hydraulic conductivity. The investigation defined the geometry of a paleochannel that ran beneath the site. This channel was the major pathway for ground water flow. The water-quality investigation determined the extent of contamination. Water samples were taken for eight indicator chemical constituents.

Nested piezometers were installed at the facility to collect immiscible as well as miscible contaminants. The water-quality study concluded that contamination was restricted to areas adjacent to the earthen pit. No plume was found to extend more than a few yards away from the pit. The remedial action plan was designed in conjunction with a permanent closure plan for the earthen pit. The plan included remedial pumping adjacent to the earthen pit and the installation of slurry trenches across the three legs of the paleochannel. The earthen pit will be closed in place and the consolidation of solid waste will be accomplished by surcharging the waste with a load consisting of a permeable liner topped with 2 feet of sand. The sand blanket will allow free liquid to escape the solid waste and be collected in a perimeter drain. The final closure will include an impermeable liner and clay cap.

Fochman, E.G., "Biodegradation and Carbon Adsorption of Carcinogenic and Hazardous Organic Compounds", EPA-600/2-81-032, Mar. 1981, U.S. Environmental Protection Agency, Cincinnati, Ohio.

This research program was conducted to determine the capability of biological treatment and activated carbon adsorption to remove chemical carcinogens and other hazardous organic compounds from water and wastewater. Compounds studied were benzidine, 4-nitrobiphenyl, 3,3-'dichlorobenzidine, benzo(g,h)perylene, benzo-(a)pyrene, dibenzo(a,h)anthracene, dibenzo(a,h)anthracene, 2-acetyl-aminofluorene, benzo(k)fluoroanthene, 4-aminobiphenyl, 3,4-benzofluoranthene, and 4-dimethylaminoazobenzene. All of the compounds tested exhibited some degree of biological degradation. Carbon adsorption was also effective in removing the compounds from aqueous solution. Large polynuclear aromatic compounds exhibited reduced adsorption capacities due to exclusion from the small diameter pores of the carbon.

Ford, C.T. and Boyer, J.F., "Treatment of Ferrous Acid Mine Drainage with Activated Carbon", Jan. 1973, Bituminous Coal Research, Inc., Pittsburgh, Pennsylvania.

Laboratory studies were conducted with activated carbon as a catalyst for oxidation of ferrous iron in coal mine water. Batch tests and continuous flow tests were conducted to delineate process variables influencing the catalytic oxidation and to determine the number and types of coal mine water to which this process may be successfully applied. The following variables influence the removal of iron with activated carbon: (a) amount and particle size of the carbon; (b) pH, flow rate, concentration of iron, temperature, and total ionic strength of the water; and (c) aeration rate. Adsorption as well as oxidation are the mechanisms involved in iron removal by this process. An evaluation of this process indicated technique feasibility which would permit acid mine drainage neutralization using an inexpensive reagent, such as limestone.

Fryberger, J.S., "Rehabilitation of a Brine-polluted Aquifer", EPA-R2-72-014, Dec. 1972, U.S. Environmental Protection Agency, Washington, D.C.

A detailed investigation was made of one (among several noted) incident where a fresh-water aquifer has been polluted by accepted disposal of oil-field brine through an "evaporation" pit (an unlined earthen pit) and later a faulty disposal well. The present extent of the brine pollution is one square mile; however, it will spread to affect 4½ square miles and will remain for over 250 years before being flushed naturally into the Red River. Detailed chemical analyses show changes in relative concentrations of constituents as the brine moves through the aquifer. Several rehabilitation methods are evaluated in detail, including controlled pumping to the Red River and deep-well disposal. None of the methods that are both technically feasible and permissible show a positive public benefit-cost ratio. Although real economic damage both present and future results from this brine pollution, rehabilitation is not now economically justified. The report emphasizes that greater effort is needed to prevent such pollution, which not only affects ground water resources but also affects water quality in interstate streams.

George, A.D. and Chadhuri, M., "Removal of Iron from Groundwater by Filtration through Coal", Journal of the American Water Works Association, Vol. 69, No. 7, July 1977, pp. 385-389.

Laboratory studies were made to compare the differences in coal and sand filtration for the removal of iron from ground water. The results were compared based on filter performance index (FPI) and retentivity. Water analysis was made on the basis of soluble iron and total ferrous iron. The authors report almost complete removal of iron in the coal and sand up to 26 hours. After 26 hours the sand filter effluent quality deteriorated. Further results at varying filter rates and influent iron concentrations showed the following: (1) coal filters can be operated effectively at 3 to 4 times the effective rate of sand filters; and (2) coal filters were more effective in removing soluble ferrous iron while both sand and coal were effective in removing ferric and insoluble ferrous iron.

Gibb, J.P., "Cost of Domestic Wells and Water Treatment in Illinois", Ground Water, Vol. 9, No. 5, Sept.-Oct. 1977, pp. 40-49.

This study provides cost information for private home ground water supply systems in Illinois. Relatively accurate cost predictions for different types and depths of wells, ranging in cost from about $150 to $2500, can be made from the graphs presented. The average cost of all wells studied is about $575. Cost data for pumping systems equipped with 10-gpm submersible pumps (approximately 50 percent of all collected data) show that the average cost of these systems is about $585, with 50 percent ranging between $400 and $680. The costs of treating water for domestic use also are summarized. Two graphs illustrate the monthly costs of softening and removing iron at varying monthly consumption rates and concentrations of hardness-forming minerals and iron. The monthly cost of continuous chlorination is calculated. Use of the data presented makes it possible to estimate the monthly costs of raw and treated water from a domestic ground water supply. Two maps show the probable costs of domestic raw water-supply systems from sand and gravel wells and bedrock wells throughout the State. For an average installation and domestic use rate in Illinois, the monthly cost of raw water is about $11.00, softened water $15.40, softened water treated for iron $22.00, and softened water treated for iron and chlorinated $25.00. Similar calculations for any type and depth of well, water quality, and treatment can be made from the information in this report. This material should provide adequate information for planning purposes and decision making in developing a desired domestic supply.

Giddings, M.T., "The Lycoming County, Pennsylvania Sanitary Landfill: State-of-the-Art in Ground Water Pollution", Ground Water, Vol. 15, No. 1, Jan.-Feb. 1977, pp. 5-14.

A 120-acre sanitary landfill was being developed for a six county area. A 20 mil (0.5 mm) PVC plastic liner lying between 2 protective layers of sand was used to prevent ground water contamination by landfill leachate. Sampling monitored the liner performance. A backup leachate treatment system existed on site to treat any detected contamination. The ground water flow at the site was confined by a thick glacial till within the underlying shale bedrock. The till was of low permeability and an artesian head existed within the bedrock system affording extra protection from ground water contamination. Operation of the landfill was by the area-fill method with 8 foot lifts up to a limit of 120 ft. To assure water quality a baseline monitoring program was undertaken to establish on-site conditions and off-site private well conditions. Two years of regulatory hearings allowed a good data base to be established. Four ground water quality monitoring wells were drilled to a depth of 150 feet (all penetrated at least 100 feet of bedrock). It was determined that the ground water is confined by the glacial till under artesian conditions. The artesian head varies from 9 feet (uphill) to 60 feet (downhill). Water exists at 80 feet below the ground surface. Analysis of "selected chemical parameters" was made from well samples. Monitoring of the ground water underdrain for conductivity was used to evaluate the efficiency of the liner. Should contamination be detected, the contaminated section was isolated and flow was diverted to a backup leachate treatment system.

Giddings, M.T., "The Utilization of a Ground Water Dam for Leachate Containment at a Landfill Site", Proceedings of the Second National Symposium on Aquifer Restoration and Ground Water Monitoring, 1982, National Water Well Association, Worthington, Ohio, pp. 23-29.

Where hydrogeologic conditions are suitable for utilization of a ground water dam for leachate containment, several advantages can be realized. Positive containment of leachate is achieved and inflow from adjacent water bodies is excluded, thereby minimizing total leachate quantity. Operating costs are limited to the pumpage cost for removal of the leachate-contaminated ground water behind the dam. Where suitable, native soils are available, construction costs can be minimized through on-site borrowing of clay to construct the dam without the need for purchasing artificial materials. Many site conditions will allow the use of standard construction equipment for excavation of the trench and for implacement of the dam so that landfill operation personnel can operate the equipment under proper engineering supervision. This case history example illustrates the utilization of a compacted clay till ground water dam from upgrading an existing landfill site to meet current design and operational requirements. On-site clay till was remolded to a permeability of 3×10^{-8} centimeters per second and keyed into a glacial till stratum underlying the landfill having an inplace permeability of 3×10^{-7} centimeters per second. Between 14 and 20 feet of sand and gravel alluvium were excavated and the dam constructed on the flood plain between the landfill and an adjacent river. Ground water quality monitoring wells located downgradient of the dam have indicated abatement of the previously existing ground water contamination due to leachate seepage from the landfill and have documented that the leachate withdrawal from a perforated pipe within a gravel envelope behind the dam is satisfactorily extracting leachate that is generated. The leachate is currently treated on an interim basis by recycling into the landfill, but will ultimately be discharged to an adjacent sanitary sewer interceptor located within the flood plain area between the ground water dam and the river.

Gillespie, D.P., Schauf, F.J. and Walsh, J.J., "Remedial Actions at Uncontrolled Hazardous Waste Sites: Survey and Case Study Investigation", Proceedings of the Second National Symposium on Aquifer Restoration and Ground Water Monitoring, 1982, National Water Well Association, Worthington, Ohio, pp. 369-374.

The purpose of this project was to investigate remedial actions applied at hazardous waste sites in the past and to demonstrate their success or failure before Superfund-sponsored cleanups were initiated. The specific objectives of this project were twofold. First, a comprehensive survey of uncontrolled hazardous waste disposal sites at which remedial actions had been practiced was performed. Remedial actions were found to have been implemented at many kinds of hazardous waste disposal facilities including some drum storage areas, incinerators and injection wells, but most frequently at landfills/dumps and surface impoundments (i.e., wastewater pits, ponds and lagoons). Contamination of numerous media included ground water, surface water, soil, air and the food chain. Waste types involved included mercury, arsenic, solvents, oil, tire wastes, organic and inorganic wastes and septic wastes. During the second phase of the project, nine states were studied in detail to document typical pollution problems and remedial actions at such uncontrolled hazardous waste sites. Remedial action technologies employed at these sites would be generally classified as either 1) surface water containment measures or 2) more sophisticated active and passive ground water control measures which were used to contain further spread of contaminant materials on the ground surface. Selected other sites utilized ground water cleanup measures including two facilities which were subjected to ground water extraction for purposes of containing and treating contaminant plumes.

Gilmer, H. and Freestone, F.J., "Cleanup of an Oil and Mixed Chemical Spill at Dittmer, Missouri, April-May, 1977", Proceedings of the 1978 National Conference on Control of Hazardous Material Spills, 1978, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 131-134.

In response to neighbor complaints of odors, fire and obnoxious smoke and deteriorating creek quality, the Missouri Conservation Commission (MCC) and the Department of Natural Resources (MDNR) made a series of investigations of the Albert Harris Property located in Dittmer, Jefferson County. These investigations, which began March 24, 1977 and continued through April 1, revealed that Mr. Harris was operating an illegal solid waste disposal site in conjunction with a container reconditioning operation. As a result of exploratory trenching and site survey, several actions were decided upon, including stream by-passing, land-fill disposal, on-site treatment and analysis of the contaminated stream water, excavation and administrative support from the U.S. Coast Guard Gulf Strike Team. On Monday, April 11, the work began as personnel and equipment arrived on scene. By Tuesday, April 12, disposal arrangements were made at a chemical landfill in Illinois.

Contaminated water impounded on the stream was pumped to a carbon adsorption column built on a design provided in an EPA research publication on field improvised water treatment systems.

The treatment system consists of three five-micron bag filters and a 100 ft^3 gravity flow carbon adsorption column built from a 12 ft long by 4 ft ID concrete culvert buried six feet in the ground on a reinforced concrete base. The culvert was filled to a depth of eight feet with carbon. The field-improvised treatment system was successfully designed, fabricated and made operational within nine days. One of the most difficult problems associated with long term post-spill treatment is not technical, however. The problem is defining willing parties to be responsible for continuing maintenance requirements. The long term effectiveness of the system is a direct function of the reliability of regularly scheduled maintenance by trained personnel.

Glover, E.W., "Containment of Contaminated Ground Water -- An Overview", Proceedings of the Second National Symposium on Aquifer Restoration and Ground Water Monitoring, 1982, National Water Well Association, Worthington, Ohio, pp. 17-22.

The containment of contaminated ground water is a difficult and expensive proposition. The initial step in developing a containment plan is to conduct a detailed hydrogeologic investigation to assess the seriousness of the problem. With the hydrologic and geologic data developed from the assessment study, a remedial containment plan is developed. The concepts used in developing the hydrogeologic study plan are briefly reviewed. Using the data developed during the hydrogeological assessment, a containment plan is developed to meet the site-specific hydrogeological conditions and nature of the contaminant. This paper reviews the current technologies available for controlling contaminated ground water and presents conditions where each may be applicable. The paper also discusses the relative effectiveness of the methods and some of the more difficult problems associated with the proper installation of the various systems. The paper concludes with a case history for a typical installation.

Graybill, L., "Evolution of Practical On Site Above Ground Closures", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1983, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 275-279.

Most closure methods are based on surface or subsurface containment barriers. The waste, however, continues to be exposed to the same hydrodynamic environmental forces as in the case of secure landfills but without the design advantages of secure landfills. Since they are located on all kinds of geological formations, the integrity and useful life of the containment method can be expected to be much less than secure landfill. The above ground closure method discussed in this paper has successfully addressed the problems associated with typical containment approaches and can be executed at a fraction of the traditional closure methods. The above ground approach differs from traditional containment methods in the following ways:

(1) The above ground method utilizes high volume waste handling techniques developed by waste disposal firms. Use of construction methods and special pumping equipment allows the economical bulk handling, manipulation and exhumation of waste at large hazardous waste sites.

(2) The above ground method uses waste solidification processes that were also developed from operating experience. The waste solidification processes allow the historic waste to be compacted into a load bearing material.

(3) The solidification and bulk handling capability allows the use of traditional civil engineering methods to design above ground closures that effectively address the environmental hydrodynamic forces operating against traditional landfills and on-site containments.

Above ground closure also offers the following advantages of conventional surface and subsurface approaches: (1) there is essentially zero risk of contaminating the uncontrolled medium of soil and ground water because the entire system is above ground, with buffer zones and failure detection systems between the waste and ground water; (2) easier access for maintenance; (3) top, walls and effluent can be visually inspected; (4) provides opportunity to detect any errant leachate prior to ground waer contamination; (5) provides easy access for future manipulation of the waste for resource recovery and new treatment methodology; (6) versatility -- the above ground cells can be used over low and high water tables and over clay and non-clay strata; (7) the design is in harmony with environmental, hydrodynamic pressure; therefore, no leachate collection system is necessary for pumping leachate up from the bottom of a landfill; (8) risk of ground water contamination is reduced in the event of geological action such as fault slippage, slumping or any other massive earth movement. Remedial action is easier, quicker and less costly. The above advantages, along with the long-term security, economics and widespread application make the above ground closure approach a powerful new tool for addressing many of the pressing hazardous waste problems in this country.

Gregg, D.O., "Protective Pumping to Reduce Aquifer Pollution, Glynn County, Georgia", Ground Water, Vol. 9, No. 5, Sept.-Oct. 1971, pp. 21-29.

Water-level declines in a principal artesian aquifer have created a head imbalance between the aquifer and an underlying brackish-water zone containing up to 4,550 mg/l chloride. The brackish-water zone leaks brackish water into the aquifer through several breaks in a confining unit. A relief well tapping the brackish-water zone was drilled near a suspected break and pumped at about 3,000 gpm to lower the potential in the zone and bring it into hydrostatic equilibrium with the aquifer. The pumping apparently succeeded in decreasing the rate of brackish-water leakage into the aquifer. Successive samples of water from a well tapping the aquifer and downgradient from the relief well showed a decrease in the chloride content. Several more relief wells may be necessary to ultimately control chloride contamination of the aquifer.

Gruber, P., "Evaluation of Ground-Water Contamination Associated with the Use of Organic Solvents at Romansville, Pennsylvania", Proceedings of the Third National Symposium on Aquifer Restoration and Ground Water Monitoring, 1983, National Water Well Association, Worthington, Ohio, pp. 69-75.

A new residential well in Romansville, Pennsylvania, produced water with an odd taste and smell. Analysis by Pennsylvania Department of Environmental Resources (PADER) revealed organic chemical concentrations ranging from 1 ppb to 11,000 ppb. Of 11 neighboring wells also tested, six showed concentrations of organic chemicals in excess of 100 ppb. The Richard M. Armstrong Co., which used trichloroethane as a degreaser, was identified as the probable source of contamination. Armstrong retained ERM to define the extent of the ground water degradation and develop an economical and technically feasible remedial action plan. ERM's work effort was designed in consultation with the PADER and Armstrong. It consisted of: an assessment of existing site data; on-site field mapping; collection of hydrological and climatological data (temperature, rainfall), and surface data (slope, percent vegetation) necessary to establish a water balance; excavation of trenches to bedrock in order to observe and describe the subsurface deposits and evidence of soil contamination; mapping of fracture traces from stereoscopic aerial photographs; drilling a new well to provide additional subsurface geological control and water quality monitoring points as well as to serve as a recharge/recovery well during remedial measures; and sampling and analysis of 58 neighboring house wells for selected organic chemicals. The remedial actions consisted of: carbon filter installation and maintenance; well purging; contaminated soil removal; and site renovation and monitoring. In addition to a carbon filter installed at the Armstrong plant, 12 carbon filters were installed in residences surrounding the facility. The treated water is monitored on a bimonthly basis. When the organic chemical concentration of the treated water exceeds the PADER recommended limits, all filters are recharged. The new well on the Armstrong site and the existing water supply wells are pumped to create a local cone of depression and prevent continued migration of ground water. Water quality monitoring has continued for nearly 18 months and has shown a slow but continual improvement in water quality in the affected wells.

Gushue, J.J., Ayres, J.E. and Snyder, A.J., "Hazardous Waste Site Investigation Sylvester Site, Nashua, New Hampshire", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1981, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 359-370.

In this paper, the authors describe the results of an engineering and hydrogeological investigation of the Sylvester Site. The investigation of the Sylvester Site and adjoining properties was designed to: (1) define the extent of soil, surface water and ground water contamination; (2) develop an engineering assessment of the hydrogeological and hydrological conditions governing contaminant movement from the site; and (3) evaluate alternative remedial actions on the basis of technical feasibility, estimated costs and environmental implications. The evaluation of remedial actions included a laboratory-scale assessment of the feasibility of removing contaminants from ground water in an on-site, above-ground water treatment plant. The final project report, including recommendations for remedial action, provided the basis for the first Federal/State cooperative agreement under Superfund, with $2.3 million being awarded to the State of New Hampshire in August 1981 for design and construction of remedial measures at the site.

Hager, D.G. and Loven, C.G., "Operating Experiences in the Containment and Purification of Groundwater at the Rocky Mountain Arsenal", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1982, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 259-261.

The Rocky Mountain Arsenal (RMA) was established by the United States Department of the Army in 1942 on approximately 20,000 acres northeast of Denver. Its mission has been to manufacture chemicals needed by the military branches of the U.S. Government. In more recent years the facilities have been used to destroy and detoxify obsolete chemical weapons and contaminated hardware as well. Since 1946, some of the facilities have been leased to a private contractor who has manufactured various types of insecticides and herbicides for commercial agricultural applications. In 1974, a portion of the RMA site was taken over by Stapleton Airport and additional land acquisition by the airport is expected in the near future. As a result of these manufacturing and demilitarization activities both soil and water have become contaminated with chemicals which are both inorganic and organic in nature. Many of the materials that were processed were either toxic and/or suspected carcinogens.

In 1974, it was discovered that several of the chemicals were being transported off site by ground and surface waters. To address this and other potential problems, a Program of Installation Restoration was established at RMA. The permanent facility for ground water containment at the North Boundary included a 6800 ft long clay slurry wall which was installed 200 ft inside the RMA perimeter. Dewatering and reinjection wells along the clay barrier remove water for treatment at a central facility and deliver the purified water back to the ground flow. The dewatering system is divided into three separate water collections systems which have waters of varying organic composition. It was anticipated that three adsorption process trains would provide added treatment flexibility than that afforded by treating a mixed influent. A pulsed bed adsorption system was selected for the permanent RMA North Boundary treatment facility. The system is comprised of three adsorbers in parallel, cartridge filters ahead of and following the adsorbers, storage vessels for both fresh and exhausted carbon and two pressure transfer vessels to move carbon between the equipment in a measured slurry volume.

Hager, D.G., et al., "Ground-Water Decontamination at the Rocky Mountain Arsenal", Proceedings of the Third National Symposium on Aquifer Restoration and Ground Water Monitoring, 1983, National Water Well Association, Worthington, Ohio, pp. 123-134.

Previous chemical production and demilitarization activities at the Rocky Mountain Arsenal near Denver, Colorado, have resulted in soil and ground water contamination at the site. Ground water flow from the arsenal now threatens nearby potable water wells. Since the initiation of an Installation Restoration Program in 1974 the migration of organic contaminants off-site has been mitigated by the installation of boundary ground water containment systems combined with granular activated carbon treatment of the ground water. Both hydraulic and slurry wall barriers have been installed to contain the flow of ground water. The water is then extracted, purified and recharged to the ground. These systems are described and operating results are presented. Ground water below the chemical production area lies in a low transmissivity zone and contains a variety of organic solvents including chloroform, trichloroethylene, carbon tetrachloride and other low molecular weight chlorinated hydrocarbons. One source control alternative under consideration in the Installation Restoration Program is to dewater, purify and recharge the ground water in the production area. To evaluate this approach a dynamic flow pilot system has been designed to examine several purification techniques for volatile organic contaminant removal. The pilot system will include aeration, catalyzed chemical oxidation and adsorption. In addition to these organic removal processes, several inorganic treatment processes will be included to assess the removal of heavy metals, hardness and silica. Preliminary studies have been conducted to provide design data for the 20 gpm pilot system. The results of these studies are reviewed and the design rationale for the pilot system is presented.

Hallberg, R.O. and Martinelli, R., "Vyredox -- In Situ Purification of Ground Water", Ground Water, Vol. 14, No. 2, Mar.-Apr. 1975, pp. 88-93.

The abundance and relative purity of ground water guarantees its increase in usage. In some localities, the content of iron and manganese in ground water is so high that these metals must be removed before the water can be used for drinking or industrial purposes. Iron occurs in two states of oxidation in nature -- the divalent (ferrous) and trivalent (ferric) forms. The Vyredox method developed in Finland and used now also in Sweden and some other countries oxidizes the ferrous ion, which is soluble in water, to the ferric ion, which is insoluble before the water enters the well. The Vyredox method achieves a high degree of oxidation in the strata around the well. The method makes use of iron-oxidizing bacteria and aeration wells. A number of aeration wells are placed in a ring around the supply well. Water is forced down the aeration wells but first it is degassed and then enriched with oxygen. The oxygen-rich water provides a suitable habitat for the iron-oxidizing bacteria which assist in the oxidation of ferrous iron. The process must be repeated at specific time intervals to avoid further increases of iron content. The process of precipitating iron in the aquifer has only a slight effect on aquifer permeability. Cloggage of the aquifer surrounding the well should not occur for a period many times longer than the life span of a typical well.

Halliburton Company, "Feasibility Study on the Application of Various Grouting Agents, Techniques and Methods to the Abatement of Mine Drainage Pollution. Part II. Selection and Recommendation of Twenty Mine Sites", Aug. 1967, Duncan, Oklahoma.

The study involved a survey of all drift mine openings in the Upper West Fork River sub-basin and the development of alternate remedial methods for the abatement of mine drainage pollution. Twenty mine sites were selected from the two hundred twenty-eight mines surveyed in the initial phase. These twenty sites are described in detail herein.

Halliburton Company, "Feasibility Study on the Application of Various Grouting Agents, Techniques and Methods to the Abatement of Mine Drainage Pollution. Part IV. Additional Laboratory and Field Tests for Evaluating and Improving Methods for Abating Mine Drainage Pollution", Aug. 1967, Duncan, Oklahoma.

The initial phase of this project involved the studies and investigations performed in the exploration of drift mines in the Upper West Fork River Sub-basin, West Virginia. Included as a part of the study was the application of various grouting agents and techniques to the abatement of mine drainage pollution. Part IV of the project is a modification of the original contract for the purpose of conducting additional field tests on methods and materials not previously evaluated in this project. The Part IV program includes an experimental test program, a seismic survey and study, and field construction tests and evaluation. The experimental test program was conducted for the purpose of determining improvements in techniques and materials previously used for remedial applications as well as consideration of different techniques which might be evaluated in field tests. The seismic survey and study included was for the purpose of locating hidden mine openings or thin high wall sections by seismic methods.

Halliburton Company, "Feasibility Study on the Application of Various Grouting Agents, Techniques and Methods to the Abatement of Mine Drainage Pollution. Part III. Plans, Specifications and Schedules for Remedial Construction at Mine No. 12-007A, Mine No. 62-067, Mines No. 64-014, 64-016, and 64-017", Nov. 1967, Duncan, Oklahoma.

The report is a continuation of previous reports concerning the studies and investigations performed in the exploration of drift mines and feasibility studies into the application of materials and material placement techniques toward the abatement of mine drainage pollution. Twenty drift mine sites were selected previously. Report II studies them. In the present report, 3 of those 20 mines were further studied. Detailed plans, specifications, and schedules for contracting and construction of pollution abatement remedial measures for each of the three selected sites is presented. This includes a general description of the three selected mines, the schedule, cost estimate and recommendations for each mine site, and the plans and specification sections for each mine.

Halliburton Company, "New Mine Sealing Techniques for Water Pollution Abatement", Mar. 1970, Duncan, Oklahoma.

The purpose was to develop and field test new concepts for watertight mine seal and bulkhead construction applicable to abatement of acid mine water pollution. Laboratory research determined proper materials, equipment and techniques for constructing mine seals or bulkheads. Field testing was conducted on remedial grouting techniques for constructing mine seals or bulkheads. Two new processes were developed. One involved a technique of placing a plug or graded limestone aggregate in a mine drift or portal to neutralize an acid mine water discharge until a seal was effected. The second process consisted of remotely constructing a mine seal including rear and front bulkheads of a self-supporting, quick-setting sodium silicate cement specifically developed for this application. A filler material of expansive cement was used between the bulkheads to complete the seal. Field testing in West Virginia substantiated the feasibility of both processes when two aggregate and two bulkhead type seals were placed in abandoned mines which had drainage flows up to 58 gallons per minute. Cost of the seals are reported.

Hammond, J.W. and Metry, A.A., "An Evaluation of In-Situ Groundwater Ion Exchange Barriers for Control of Low-Level Radioactive Wastes", undated, Roy F. Weston, Inc., West Chester, Pennsylvania.

This paper presents a methodology for control of ground water contamination resulting from shallow burial of low-level radioactive waste. Such sites fall in one of the following categories: (1) Formerly Utilized Site Remedial Action Project (FUSRAP); (2) Uranium Mill Tailings Remedial Action Project (UMTRAP); and (3) Remedial Action of Inactive Commercial Low-Level Radio-active Waste Disposal Sites. In the past few years a great deal of experience has been gained in the design of low-level radioactive residuals disposal facilities and remedial action rehabilitation plans for existing low-level radioactive facilities and waste disposal sites. During many projects, the following have been identified as feasible techniques to protect public health and the environment: (1) use of ion-exchange media as part of the liner or barriers for radionuclides attenuation; (2) use of a cover system for radon gas control and attenuation; (3) containment and isolation of the site using a surface cap; (4) use of a liner system beneath waste material for containment and encapsulation; (5) hydrogeologic isolation of affected aquifer by bentonite slurry walls; (6) in-situ grouting, solidification, conditioning, and chemical or thermal stabilization; (7) use of passive ground water treatment systems; (8) application of overall site management and closure techniques; and (9) environmental management, surveillance, and monitoring. For given projects, the optimum design may include various combinations of these techniques, depending on site-specific characteristics. The proper selection and specification of a technique requires an understanding of the principal involved and methodology used for evaluation. This paper presents a discussion of ion exchange properties of barriers or liners as passive means of attenuation of radionuclides and protection of ground water quality.

Hanson, J.B., et al., "Hazardous Substance Response Management Model", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1981, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 198-200.

> The Environmental Protection Agency (EPA) is now using on an interim basis a Hazardous Substance Response Model as a management tool to lead governmental project managers through the activities related to cleaning uncontrolled releases of hazardous substances. Response funds are available primarily from the Comprehensive Environmental Response Compensation and Liability Act of 1980, P.O. 96-510 ("CERCLA" or "Superfund"). The Model presents in Flow Chart form a suggested master network of activities designed to orchestrate a cleanup project in a manner that approximates the process of response currently being used on an interim basis by the EPA. The Model, in its completed form, is currently being developed and will include management-related activities, community relations, government/agency coordination, contractor procurement, contractor monitoring and technical decision-making. The goals of the Model are: (1) to describe the activities necessary to manage cleanup of an uncontrolled hazardous waste site; and (2) to present this information in a form that is easy to understand, and which will assist those responsible for the day-to-day management of a project. In short, it is comprehensive in scope and designed for practical use. The Model is a vehicle incorporating the requirements of CERCLA with the experience of the people who are well-versed in evaluating, planning and cleaning releases.

Harris, M.R. and Hansel, M.J., "Removal of Polynuclear Aromatic Hydrocarbons from Contaminated Groundwater", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1983, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 253-265.

> Reilly Tar and Chemical Corporation operated a coal tar distillation and wood preserving plant in St. Louis Park, Minnesota, between 1918 and 1972. Reilly disposed of wastes from the operation consisting of a mixture of many compounds, including a class of organic compounds known as Polynuclear Aromatic Hydrocarbons (PAH), some of which are carcinogenic, in a network of ditches that discharged to an adjacent wetland. In the mid-1970's concerns were raised relative to PAH in ground water in the area. This paper presents bench-scale and pilot-scale testing data for a variety of water treatment technologies, illustrating the degree of treatment achievable with each technology. Influent and effluent concentrations are reported for 34 PAH and other coal tar derivative compounds. Three of the technologies tested (GAC, O_3/US and H_2O_2/UV) achieved compliance with project specific treatment goals and provided effluent water quality adequate for use in a potable water distribution system.

Harsh, K.M., "In Situ Neutralization of an Acrylonitrile Spill", Proceedings of the 1978 National Conference on Control of Hazardous Material Spills, 1978, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 187-189.

At 2:52 p.m., June 11, 1974, an east bound Chessie System Freight train hit an obstruction placed on the tracks by vandals and derailed about 6 miles east of Dayton, Ohio. A tank car containing 133,300 pounds of Acrylonitrile was punctured and caught fire. The plume from the fire was visible for 6-10 miles. Local fire departments and disaster agencies responded quickly and put out the fire by about 4:30 p.m. By 1:00 p.m., on June 14, the Ohio EPA had decided that the acrylonitrile would be neutralized by chemical action upon the cyanide portion of the acrylonitrile molecule. The oxidation of the cyanide/acrylonitrile would be accomplished by first raising the pH of the acrylonitrile contaminated area above 10, with lime and then spraying chlorine over the area. On Monday, June 17, and Wednesday, June 19, monitor wells were drilled on all sides of the spill. Samples were also taken of the affected area to determine if the neutralization had been successful. Samples taken for an extended time period from the monitor wells showed no acrylonitrile, and therefore the operation was a success.

Headworth, H.G. and Wilkinson, W.B., "Measures for the Protection and Rehabilitation of Aquifers in the United Kingdom", Proceedings of Conference on Groundwater Quality: Measurement, Prediction and Protection, 1976, Water Research Centre, University of Reading, Berkshire, England, pp. 760-817.

At present about 30% of public water supply in the United Kingdom is derived from ground water sources, and regional schemes for future development are now being planned and implemented. However, there is an increasing demand for these aquifers to fill a multiple role in water supply, waste disposal, and as sources of construction material. It is, therefore, appropriate that authorities concerned with water supply and waste disposal, and the associated organizations, are now directing their attention towards the best use of these aquifers while attempting to resolve the problems arising from their conflicting functions. Water authorities have a statutory duty and are currently engaged in reviewing the use and management of their water resources and in drawing up future plans. Thus there is an opportunity to prepare a long-term policy for the protection of ground water quality. This paper firstly categorizes the principal sources of pollution and the ground water development conditions that will lead to contamination of underground resources. The control and rehabilitation measures that may be adopted for existing and potential pollution situations are described and illustrated by a number of case histories.

Hemsley, W.T. and Koster, W.C., "Remedial Technique of Controlling and Treating Low Volume Leachate Discharge", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1980, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 141-146.

A landfill was ordered to be closed by the Pennsylvania Department of Environmental Resources. The landfill had an uncontrolled leachate discharge which the State ordered to be remedied. The problem of collecting leachate after-the-fact from certain areas of the landfill was strictly hydrogeological in nature. How much leachate was generated had to be determined for the design of a treatment system of adequate capacity. This was a question that could only be solved through hydrogeological analysis. It was determined that the peak discharge rate of leachate was 7.9 gpm/acre. Treatment of small volumes of highly concentrated leachate is by chemical addition, settling, and activated carbon filtration. This paper discusses the procedure of the hydrogeologic methods employed, and the treatment plant design including its capital and operating expenses.

Hill, R., Schomaker, N. and Wilder, I., "Uncontrolled Hazardous Waste Site Control Technology Evaluation Program", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1982, Hazardous Material Control Research Institute, Silver Spring, Maryland, pp. 233-236.

In anticipation of the passage of the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA or Superfund), the Office of Research and Development, of the USEPA began a program in 1980 to support the Agency's activities concerned with uncontrolled hazardous waste sites. Since CERCLA only provided for a five year program for the uncontrolled hazardous waste site problem, time was not available to establish a fundamental research and development program. The approach taken by the Agency for the Office of Research and Development was one of technical support to the Office of Emergency and Remedial Response. Technologies that had been developed under the Clean Water and Solid Waste programs were adapted to the uncontrolled hazardous waste site situations. In addition, construction techniques, e.g., slurry trench cutoff walls, injection grouting, and chemical stabilization, that had been used for other purposes, were evaluated to determine their applications to uncontrolled sites. Also there were very limited data available on the cost and effectiveness of various remedial techniques. The task of collecting and analyzing the available data was initiated. Once CERCLA became law, the Office of Research and Development developed, in consort with the Office of Emergency and Remedial Response, a five year support strategy which is updated each year. The srategy outlined a program with peak funding in the early years to meet the immediate needs of the program; the latter years concentrates on technical assistance.

Holmes, J.G. and Kreusch, E.G., "Acid Mine Drainage Treatment by Ion Exchange", Nov. 1972, Culligan International Co., Northbrook, Illinois.

In areas where acid mine drainage has diminished the available water supplies, processes which are capable of producing potable water from this drainage are of interest. Ion exchange processes have this capability. The investigation was intended to study several conventional ion exchange processes, using commercially available materials and to determine if any of these processes could be used to produce potable water from acid mine drainage. The three best systems were found to be: strong acid cation exchanger regenerated with sulfuric acid; weak base anion exchanger regenerated with caustic soda; and weak base anion exchanger regenerated with sodium hydroxide and carbon dioxide (modified Desal process). Treatment plants in three sizes were designed for each system so that cost estimates could be established.

Horizons, Inc., "Foam Separation of Acid Mine Drainage", Oct. 1971, Cleveland, Ohio.

Laboratory studies of continuous flow foam separation were conducted to determine the optimum conditions for maximum extraction of dissolved metal cations (Fe, Ca, Mg, Mn, and Al) from acid mine drainage. Foaming experiments were conducted in a 6 in.-diameter glass column capable of liquid flow rates of 3-12 gal. per hour. The approach to foam separation taken was the production of the persistent foams which allowed protracted foam drainage to reduce liquid carry-over in the foam. The effects of pH, chelate addition, surfactant type and concentration, air sparging rate, metal concentration and foam drainage were investigated in relation to metal extration. Results show that sewage foamability is too low for foam separation alone to be a feasible sewage treatment method.

Huibregtse, K.R. and Kastman, K.H., "Development of a System to Protect Groundwater Threatened by Hazardous Spills on Land", EPA-600/2-81-085, May 1981, U.S. Environmental Protection Agency, Cincinnati, Ohio.

Treatment of hazardous materials spills onto land that create threats to the quality of ground water is frequently limited to excavation or flushing of the area with water. The purpose of this project was to establish an alternative approach to the solution of the problem. The objective was to develop, design and construct a vehicle capable of containing about a 40 m^3 (10,000 gal) hazardous spill on contaminated land and treating the polluted soils by oxidation/reduction, neutralization, precipitation or polymerization. The approach was to use direct injection of grout into the soil around the contaminated area to envelop the spill and isolate it from the ground water, nd detoxify the spill area by injection of treatment agents. Since information regarding this approach was minimal, both laboratory and pilot-scale tests were performed before the unit was designed, constructed and delivered to the U.S. Environmental Protection Agency in Edison, New Jersey.

Treatability tests were performed on four soil types (gravel, sand, silt and clay) with three reaction types (oxidation/reduction, neutralization and precipitation). Flow-through tests were performed to simulate conditions in gravel, sand and silt while sealed tests were performed to approximate conditions in clay soils. Detoxification in flow-through tests exceeded 99 percent of the initial contaminant added and appeared to be the result of both displacement and chemical reaction. Sealed test detoxification efficiencies in clays ranged from 56.5 to 99.5 percent. Formation of insoluble products did not adversely affect detoxification. A simultaneous evaluation of grout formulations and injection devices indicated that grouting was most applicable in gravel, sand and some silty soils. The direct driving of heavy duty pipe is recommended to minimize short-circuiting and to lower costs. Two types of grout (bentonite/cement and sodium silicate) were selected as most applicable.

A mobile in-situ containment/treatment unit was designed, constructed and mechanically tested before it was delivered to EPA. Major components located on a 12.1 m (43 ft) drop deck trailer include: a diesel electric generator, an air compressor, two 2.46 m^3 (650 gal) lined tanks with mixers, four 0 to 30 lpm (0 to 8 gpm) progressive cavity pumps, four 0 to 76 lpm (0 to 20 gpm) air diaphragm pumps, a control panel, flow controls and a solids feed conveyor. Decision guidelines for unit mobilization and an operations and maintenance manual were provided with the containment treatment unit.

Intorre, B.J., et al., "Evaluation of Ion Exchange Processes for Treatment of Mine Drainage", Jan. 1973, Burns and Roe Construction Corporation, Paramus, New Jersey.

Laboratory and pilot plant research work was conducted on a modified Desal, Sul-biSUL, and conventional ion exchange processes to evaluate their performance on acid mine drainage feed waters. The study included process variables, analytical techniques, daily monitoring of acid mine drainage source, and economics of potable water production. This work was carried out at the Acid Mine Drainage Demonstration Plant at Hawk Run, Pennsylvania. Disposal of wastes was explored briefly.

James, S.C., Shuckrow, A.J. and Pajak, A.P., "History and Bench Scale Studies for the Treatment of Contaminated Groundwater at the Ott/Story Chemical Site, Muskegon, Michigan", *Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1981*, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 288-293.

> Hazardous leachates and contaminated ground and surface waters are often associated with unsecured industrial waste storage and disposal sites. Numerous problems are encountered in the cleanup of such a site. One major problem is identifying the most effective treatment technology for the contaminated stream. Contributing to this problem are: (1) the inability to characterize completely the contaminated stream due to technical and economical limitations; (2) the paucity of information on the effectiveness of techniques for treating the broad spectrum of organic and inorganic compounds frequently present in these streams. Therefore, the U.S. Environmental Protection Agency began a project to evaluate techniques for concentrating hazardous constituents of aqueous waste streams. A literature review, desktop evaluation and laboratory bench scale experimental studies form the basis for judging the potential of numerous candidate technologies. During the course of this project, a part of the laboratory experimental work was carried out at Cordova Chemical Company, present owners of the Ott/Story Site, using ground water contaminated by prior operations. This site provided an opportunity to interface research activities with development of a treatment system for a high priority problem site. In this paper, the authors provide a brief background on the site history, a method selection of candidate treatment technologies and summary of results of the experimental studies.

Jhaveri, V. and Mazzacca, A.J., "Bio-reclamation of Ground and Groundwater Case History", *Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites*, 1983, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 242-247.

> In Aug. 1975, contamination was observed in a small creek that discharges into Allendale Brook in New Jersey. A storm sewer line that discharges into the stream was a point source of pollution. Data obtained in Nov. 1975 indicated the contamination was coming from Biocraft Laboratories, Inc., a semi-synthetic penicillin manufacturing plant located nearby. Biocraft's investigation revealed a leak in an underground process line that carried a mixture of methylene chloride, acetone, n-butyl alcohol and dimethyl aniline. This mixture infiltrated into the storm sewer line in front of the building which was the point source of contamination.

On Nov. 24, 1975, all underground lines were disconnected and above ground lines installed. The investigation failed to determine when the leak started. Based on daily tank inventory readings from June 1972 when the plant started up, it was estimated that the following amounts of substances may have leaked into the subsurface: methylene chloride -- 181,500 lb; n-butyl alcohol -- 66,825 lb; dimethyl aniline -- 26,300 lb; and acetone -- 10,890 lb. The biostimulation-decontamination system consists of the following major components: (1) a ground water collection system down gradient of the contamination area; (2) a four-tank, dual aerobic biological treatment system; (3) a series of in situ aeration wells along the path of ground water flow; (4) effluent injection trenches up gradient of the contaminated area; and (5) a control room. The biostimulation process implemented at the Biocraft site is reducing pollutant concentrations in the ground and ground water. Chemical analyses of ground water for selected pumping and monitoring wells prior to the startup of the continuous process and after two years of operation strongly indicate a gross reduction of contamination in ground water. This demonstrates that biostimulation can be successful not only in relatively permeable but also in low permeable formations.

Jones, A.K., et al., "Coverings for Metal Contaminated Land", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1982, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 183-186.

The information derived from this project has shown that the measures used for restoration of metal contaminated land have been successful. In general, where covering has been carried out in accordance with recommendations there is no evidence that regression due to reappearance of toxicity will occur. Toxicity problems still exist at some sites due to areas of contaminated material remaining uncovered. At some sites the provision of an insufficient depth of cover has resulted in toxic concentations of metals within plant rooting zones causing adverse effects and in some cases, death of vegetation. These investigations at reclaimed sites have produced no evidence of upward migration of metals into covering layers through transport of metals in solution in capillary water under field conditions. At some sites elevated metal concentrations in surface covers have occurred through physical incorporation of contaminated materials into the amendments during restoration work. At two sites where chromium is present in a soluble anionic form, contamination of the surface covers with resulting toxicity to vegetation has occurred where water enters waste mounds, becomes contaminated, and re-emerges through the covering layers at lower levels. At none of the sites was there any evidence of similar movement of cationic metal ions through soil covers.

Kaschak, W.M. and Nadeau, P.F., "Remedial Action Master Plans", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1982, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 124-127.

The Remedial Action Program has been developed to respond to releases of hazardous substances from the 400 sites comprising the National Priorities List under the commonly known Superfund Program. These sites may require long-term cleanup actions to provide adequate protection of public health, welfare and the environment. The Interim Priority List, which identified 115 sites eligible for remedial funding, was published on Oct. 23, 1981. This list was expanded to 160 sites on July 23, 1982. As the program expands and the National Priorities List of 400 sites is published, an effective long-range planning mechanism becomes essential. An effective technical and financial planning document which has been developed to assist with the long-range planning needs of the USEPA is the Remedial Action Master Plan or RAMP. In this paper, the authors discuss the deelopment of the RAMP and its current and future uses as a planning tool for conducting remedial activities at uncontrolled hazardous waste sites, and outlines the basic structure and contents of the RAMP with the use of an illustrative example.

Kastman, K.H., "Remedial Actions for Waste Disposal Sites", Proceedings of Fourth Annual Madison Conference of Applied Research and Practice on Municipal and Industrial Waste, 1981, Department of Engineering and Applied Science, University of Wisconsin-Extension, Madison, Wisconsin, pp. 131-150.

The current problems associated with waste disposal sites which are polluting the environment have received much public attention in the last few years. The situations can be extremely complex and many of the techniques for mitigating the contaminant effects are marginally effective, or extremely costly. Also, those faced with solving specific problems may not have sufficient information available to determine the best type of remedial action which may be implemented. This paper provides a state-of-the-art review of specific remedial actions which are available to reduce or eliminate ground water and subsurface contamination problems at existing waste disposal sites.

Kaufmann, H.G., "Cost-Effective Treatment of Organically Contaminated Potable Well Waters", Proceedings of the Second National Symposium on Aquifer Restoration and Ground Water Monitoring, 1982, National Water Well Association, Worthington, Ohio, pp. 94-98.

During the past several years, more and more emphasis has been placed on the quality of ground water that is being used as a source of municipal potable drinking water. The identification of large numbers of chemical, sanitary and hazardous dump sites throughout the country illustrate the potential, and in many cases, actual contamination of ground water. Evidence of contamination with synthetic organic chemicals that were disposed of in prior years is now being found. Once organic chemical contamination of a municipal well water is detected, several options are immediately exercised: close down the well; buy bottled water; buy water from adjacent communities; do nothing; drill new wells upgradient of the source of contamination; or treat the contamination. This paper deals with the option of cost-effectively treating the municipal well water before it is pumped to the distribution system. The paper discusses municipalities which reviewed the available options. Granular activated carbon systems were installed by these municipalities for the removal of the organic chemical compounds. Data is presented illustrating the removal efficiencies of the granular carbon systems. The capital and operating economics of the systems are presented. Economics illustrating treatment costs in the range of 40 cents to $1 per capita per month utilizing the service system approach are presented.

Kelleher, D.L. and Stover, E.L., "Investigation of Volatile Organics Removal", Presented at the New England Water Works Association Meeting, Jan. 1980, Randolph, Massachusetts.

Organic contaminations were detected from the well supply in the town of Norwood, Massachusetts. This prompted the Dedham Water Company to consider the possible interaction of ground water between the Norwood wells and its own White Lodge well field in Westwood. The Company's well field consisting of four conventional gravel-packed wells with depths ranging from 70-76 feet, has an estimated safe yield of 4.5 mgd. Organic analyses indicated the presence of more than 35 ppb, suggested maximum contaminant level, of 1,1,1, trichloroethane (TCEA) in two of the wells while the other two contained less than 35 ppb.

Pilot plant tests were conducted to evaluate methods for organic removal, particularly TCEA and iron and manganese removal which were capable of meeting not only current regulations but also any more stringent regulation not yet mandated. The treatment alternatives were: air stripping for volatile organic removal and possible oxidation of manganese and subsequent removal, activated carbon for volatile organics removal, and ion exchange for manganese removal. Parallel air stripping and carbon adsorption pilot studies were conducted for volatile organics removal. The system consisted of 4-inch diameter glass columns packed with 6 mm glass Raschig rings, supported by a stainless steel screen. The system was allowed to stabilize at each operating condition (various air and water flow rates) prior to collecting samples to ensure representative samples and to eliminate start-up effects. Analyses of the volatile organics were conducted with a gas chromatograph utilizing the purge and trap method. The carbon pilot system conducted consisted of 4 glass columns of 4 inch inside diameter by 5 feet in length. These columns were operated in series in the downflow mode during the 72 day test period. The carbon exhaustion rates and required contact time to achieve the desired effluent quality were also determined. Volatile organics were analyzed for the well water before and after treatment. The feasibility of employing aeration and glauconite or greensand were evaluated for iron and manganese removal. The pH of the well water was raised to 9.0 with caustic and vigorously aerated. The manganese greensand was formed by treating glauconite with manganese salt. The exhausted media was regenerated by applying potassium permanganate to oxidize the adsorbed material. An intermittent aeration technique, operating under constant head, was also employed. Samples were analyzed for manganese, iron, pH and turbidity.

TCEA removal efficiencies by air stripping were 87 percent and 74 percent with an air-to-liquid ratio of 30.1 to 1.0 for the two contaminated wells. A composite mix of water from both the wells at an air to liquid ratio of 26.5 to 1.0 gave an 82 percent removal efficiency. The four carbon adsorption pilot columns were able to reduce TCEA and TOC to less than 1.0 ppb and 0.5 ppm, respectively. The carbon exhaustion rate and the carbon retention time required for design was determined by comparing the TCEA carbon adsorption loading rate to the retention time of specific effluent quantities. A retention time of around 15 to 20 minutes yielded the highest carbon adsorption loading rate and lowest carbon exhaustion rate. Hence, approximately 1.4 pounds of carbon per 1,000 gallons of water is required for an influent of about 100 ppb. Aeration did not prove to be a feasible method of manganese removal, but the adsorption technique by greensand filter was found to be effective. The least expensive alternative evaluated was air stripping and manganese greensand filtration whereby TCEA concentration could be effectively stripped to less than 10 ppb.

Kelly, W.E., Powers, M.A. and Virgadamo, P.P., "Control of Groundwater Pollution at a Liquid Chemical Waste Disposal Site", Studies in Environmental Science: Quality of Groundwater, Vol. 17, 1981, Elsevier Scientific Publishing Company, Amsterdam, The Netherlands, pp. 273-278.

Waste chemicals dumped in open pits have polluted ground water and nearby domestic wells. The existing situation has been evaluated by field studies and predictions tested with analytic dispersion models. A renovation scheme involving recovery of contaminated ground water, air stripping and vapor recovery, and recharge to the ground water has been developed and approved for final design.

Kerfoot, W.B., "Direct Measurement of Gasoline Flow", Proceedings of the Third National Symposium on Aquifer Restoration and Ground Water Monitoring, 1983, National Water Well Association, Worthington, Ohio, pp. 396-401.

Direct measurement of gasoline flow on top of ground water provides rapid information on direction and rate of movement. Two procedures can be used for calibration: directly if a sufficient volume of strata is available; or indirectly, utilizing a conversion of the hydraulic conductivity of ground water versus petroleum product. Careful selection of well screen should be followed if measurements are made inside monitoring wells. Swelling of PVC can cause closure of slit widths less than 20/1,000 width. During recovery of gasoline product, the efficiency of collection can be monitored to assure efficient operation. Mapping of the zone of depression provides on-site information on rate of withdrawal and intercepted zone of flow. Several useful formulas are given for estimating time to recovery and anticipated volume.

Knox, R.C., "Effectiveness of Impermeable Barriers for Retardation of Pollutant Migration", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1983, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 179-184.

One of the most popular current methods of containing contaminated ground water is through the use of subsurface impermeable barriers. These barriers can take one of three forms: slurry walls; grout curtains; or steel sheet-piles. Successful operation of these barrier systems depends upon three basic criteria. First, the barrier must be truly impermeable and remain so even upon exposure to the contaminated ground water. Second, there must exist an underlying impermeable formation, at a reasonable depth, to which the barrier can be connected. Third, an adequate connection between the barrier and the underlying formation must be assured. In this paper, the author presents the results of the analysis of the movement of contaminated ground water under or through an imperfect barrier. The first phase of the analysis consists of the development of an analytical solution for the flow of ground water under a barrier and a simple numerical integration technique for developing concentration breakthrough curves. This simple solution algorithm was applied to the cases of variable recharge rates and lengths, variable depths of penetration of the barrier and anisotropic soils. The second phase of the analysis involves applying a numerical solute transport model to analyze the performance of a barrier with and without the effects of hydrodynamic dispersion, in the presence of a layered soil and a fully penetrating but partially permeable barrier.

Kosson, D.S. and Ahlert, R.C., "Treatment of Hazardous Landfill Leachates Utilizing In-Situ Microbial Degradation", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1983, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 217-220.

Industrial wastes have been frequently placed in landfills, lagoons and uncontrolled dump sites, subsequently producing liquid residuals as the result of compaction, rainfall runoff and infiltration, and biodegradation. These liquids can leach from a disposal site and contaminant underlying ground water and adjacent surface waters. An in situ treatment process for treatment of aqueous landfill leachates has been developed. Transport of hazardous materials is avoided, offering safety and economic advantages. A combination of physical, chemical and biological processes results in effective ultimate disposal. Landfill leachate is pretreated to remove suspensions, dispersed oil and heavy metals. Subsequently, treatment is effected with a land based biological process. Utilizing aerobic and anaerobic degradation processes associated with mixed microbial populations, hazardous waste treatment is viewed as proceeding either in the landfill structure or in a neighboring soil system.

Kraus, D.L. and Dunn, A.L., "Trichloroethylene Occurrence and Ground-Water Restoration in Highly Anisotropic Bedrock: A Case Study", Proceedings of the Third National Symposium on Aquifer Restoration and Ground Water Monitoring, 1983, National Water Well Association, Worthington, Ohio, pp. 76-81.

A study was conducted to determine the extent of ground water contamination by trichloroethylene (TCE) and possible aquifer restoration methodologies at a manufacturing facility in southeastern Pennsylvania. Analysis of soil samples collected from the site showed that the contamination originated in an area near the plant machine shop. Approximately 30 cubic yards of soil containing up to 68,000 ppb TCE was subsequently excavated and transported to a state-approved disposal site. Initial ground water samples collected from residential and commercial wells in the area indicated that the contamination appeared to be confined to the plant property. To more accurately define the extent of TCE occurrence, a monitoring well network was installed on plant property. A recovery well was drilled at the TCE source, with its discharge routed through a counter-curent air stripper for TCE removal. Pumping tests showed a very strong hydraulic connection between the recovery well and one of the downgradient monitor wells, while the remaining monitor wells showed little, if any, effects from pumping. Shortly after recovery began, the hydraulically-connected downgradient well showed significant increases in TCE concentrations, indicating that the plume had extended beyond this well and was being drawn back toward the recovery well. This indicated that TCE transport was possibly fracture-controlled and that the ground water recovery program would be an effective method for aquifer restoration.

Kufs, C., et al., "Alternatives to Ground Water Pumping for Controlling Hazardous Waste Leachates", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1982, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 146-149.

Many techniques are available for controlling ground water contamination from hazardous waste management facilities including pumping, removal (excavation), subsurface drains, low permeability barriers, and in situ treatment. Ground water pumping systems are very commonly used because of their large range of applicability and low installation costs. Pumping systems can be designed to perform almost any function such as adjusting potentiometric surfaces, containing leachate plumes to prevent further migration, and removing contaminated ground water. The chief technical advantages of pumping systems are: applicability -- usable in confined and unconfined aquifers of rock or unconsolidated materials under any conditions of homogeneity and isotropy; design flexibility -- usable for injection as well as extraction regardless of the depth of contamination; construction flexibility -- able to be installed using a variety of readily available materials by most qualified well drillers; and operational flexibility -- easy to repair most systems components or modify the system or its operation as site conditions dictate. Although there are many advantages to using ground water pumping techniques, some distinct disadvantages to their use exist. The main technical disadvantages of pumping are that it requires: extensive design data -- on the site's hydrogeology and leachate characteristics so that the system's components and operating conditions can be designed or selected properly; effluent treatment -- or some other means of managing well discharges; continuous monitoring -- to verify adequacy of system design and function and to safeguard against component (e.g., pump) failure which can result in contaminant escape; permeable aquifers -- otherwise the system cannot function efficiently or effectively; leachate compatibility -- in terms of the leachate's ability to move in ground water to the wells and no deteriorate well materials; and dilution -- leachate may significantly dilute with ground water making it necessary to pump larger volumes of ground water to remove contaminant. Of these requirements, aquifer permeability and leachate compatibility are the most common reasons for seeking an alternative to ground water pumping.

Probably the single most significant drawback to using ground water pumping is the high operation and maintenance (O&M) costs typically associated with the system after installation. Many times this is overlooked in remedial action planning especially when capital (installation) costs are much higher for other options. Minimizing long-term costs is particularly crucial to site remediation under Superfund, because states must pay all O&M costs. Key O&M costs for pumping systems include: treating the contaminated discharge, providing electricity for the pumps, maintaining and repairing system components, and monitoring system performance. While other remedial actions also have these O&M costs associated with them, pumping costs are frequently higher because system operation is more demanding. For example, a subsurface drain may require the same amount of effluent treatment, maintenance, and monitoring as a pumping system. However, electrical requirements will be lower because the leachate is collected by gravity flow. Low permeability barriers will have very low O&M costs, especially if leachate treatment is not required. Consequently, these techniques may be more cost effective than pumping in the long run even though their installation costs are higher. In the remaining sections of this paper, the authors describe alternate technologies for controlling ground water contamination in cases where pumping is inappropriate. Also discussed are the conditions under which an alternate technology might be a more effective remedial action than pumping.

Lafornara, J.P., et al., "Soil Surface Sealing to Prevent Penetration of Hazardous Material Spills", Proceedings of the 1978 National Conference on Control of Hazardous Material Spills, 1978, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 296-302.

The problem of control of chemical spills on land has recently received a great deal of attention from the public, in general and the technical community, in particular, due at least in part to several incidents throughout the country where ground water has been contaminated. Most of the scientific activity in this area has been in the monitoring and health effects areas but little has been done to develop methods to alleviate or mitigate the problem of the contaminated ground water. Presently, mitigating action involves either the physical removal of the soil from the spill-impacted area and disposing of it at a secure landfil or the drilling of "cone of influence" wells followed by the removal of the pollutant from the water by conventional treatment technology. These techniques are both time consuming and expensive.

It is the purpose of this program to develop an alternative method to mitigate the effects of land spills and thereby protect the nation's ground water resources. The main thrust of this alternative will be to prevent a spilled chemical from reaching an aquifer in the first place. This will be accomplished by soil surface sealing.

Lakshman, B.T., "Is it Feasible to Clean the Aquifer Once it is Contaminated by Landfill Leachate?", Studies on Environmental Science: Quality of Groundwater, Vol. 17, 1981, Elsevier Scientific Publishing Company, Amsterdam, The Netherlands, pp. 1065-1072.

> In this paper an attempt is made to critically examine the implications and experiences of ground water contamination due to landfill leachate in the State of Delaware in particular, and the United States of America in general. The feasibility of cleaning such contaminated aquifers through abatement programs has also been weighed and analyzed. Also discussed in general are other sources of contamination contributing to the impairment of aquifers used for potable water supplies.

Lamarre, B.L., McGarry, F.J. and Stover, E.L., "Design, Operation and Results of a Pilot Plant for Removal of Contaminants from Ground Water", Proceedings of the Third National Symposium on Aquifer Restoration and Ground Water Monitoring, 1983, National Water Well Association, Worthington, Ohio, pp. 113-122.

> The ground water at the Gilson Road Hazardous Waste Site in Nashua, New Hampshire, was contaminated with several million gallons of volatile organic solvents, extractable organics, various heavy metals sludges and leachate from domestic refuse. A detailed analysis of the site conditions and the likely effects of the surrounding environment identified a two-part remedial action program as the most cost-effective solution. The plume of contaminated ground water has been partially isolated by surrounding it with a slurry wall and membrane surface cap. Depth to bedrock varied from 30 to 110 feet around the 20-acre site. Bedrock beneath the site is highly fractured and the glacial till discontinuous, leading to the possibility of significant leakage from the contained area. Also the potential for eventual leakage through the slurry wall due to chemical degradation is high. The concentration of organic solvents in the ground water is approximately 0.2 percent by weight. A ground water treatment system was proposed to reduce the contaminant concentration by approximately 90 percent, based on bench scale treatability studies. A 20 gpm pilot plant was designed, built and operated to establish the cost-effectiveness of several process alternatives and to establish firm design parameters for the full scale (300 gpm) plant. Processes piloted included metals removal by chemical neutralization and precipitation, high temperature air stripping, biological treatment, distillation and incineration. The key process and economic factor is disposal of the concentrated organic solution.

Landon, R.A. and Sylvester, K.A., "Delineation of Subsurface Oil Contamination and Recommended Containment/Cleanup, U.S. Naval Station, Norfolk, Virginia", Proceedings of the Second National Symposium on Aquifer Restoration and Ground Water Monitoring, 1982, National Water Well Association, Worthington, Ohio, pp. 335-338.

A hydrogeologic investigation was conducted at the Norfolk, Virginia, Naval Station to delineate the subsurface occurrence of fuel oil and associated hydrocarbon products at two bulkhead locations. The initial phases of this investigation entailed the drilling of test borings and the excavation of numerous backhoe pits to delineate the areal extent of oil products. Small-diameter monitoring wells were constructed to afford periodic monitoring of the occurrence and thickness of oil products on a fluctuating ground water table. Numerous water/oil measurements were made to determine and assess the effects of recharge from rainfall, normal tidal fluctuations and storm tidal fluctuations relative to locally significant changes in the occurrence and thickness of oil. A French drain interceptor trench was recommended for oil recovery and cleanup. This trench was installed in conjunction with bulkhead repair and reconstruction. An additional use of the trench would be to monitor and recover any future oil leaks or spills.

Larson, R.J. and Ventullo, R.M., "Biodegradation Potential of Ground-Water Bacteria", Proceedings of the Third National Symposium on Aquifer Restoration and Ground Water Monitoring, 1983, National Water Well Association, Worthington, Ohio, pp. 402-409.

The biodegradation potential of bacteria in ground water was examined using representative natural and xenobiotic compounds such as carbohydrates, amino acids, industrial chemicals and pesticides. Trace amounts (ppb level) of ^{14}C-labeled organic compounds were added to replicate samples and the amount of carbon assimilated (^{14}C into biomass) and/or respired to $^{14}CO_2$ ($^{14}CO_2$ evolved) was measured. Turnover times, the amount of time required to remove the in situ level of substrate present, maximum velocities (V_{max}) and biodegradation rate constants were calculated from these data. The abundance of bacteria was assessed by plate counts (PC) and acridine orange direct counts (AODC). Overall, the abundance and activity of the ground water microbial communities were comparable to values obtained in oligotrophic surface water. AODC were on the order of 10^6 ml^{-1} and PC, 10^3-10^4 ml^{-1}. Turnover time values for natural compounds ranged from 90-200 hr, whereas the values for the xenobiotic compounds were two- to 30-fold higher. Surfactants exhibited the most rapid rates of degradation of the industrial chemicals tested ($V_{max} \sim 120$ ng/l/hr), whereas pesticides exhibited the slowest rates ($V_{max} \sim 2$ ng/l/hr). For most of the ^{14}C-pesticides tested, mineralization of the carbon skeleton to $^{14}CO_2$ was not observed and utilization of these compounds as carbon and energy sources by ground water bacteria could not be demonstrated.

Lee, G.W., Jr., et al., "Investigation of Subsurface Discharge from a Metal Finishing Industry", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1983, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 346-351.

> An order was issued to a metal finishing and manufacturing facility in Aug. 1981. The document required that a complete hydrogeological investigation pertaining to the subsurface discharge of 1,1,1-trichloroethane which allegedly migrated through the ground water system to a nearby Town water supply well be performed. An investigation was performed which included the installation of ground water monitoring wells, soil and ground water sampling and research oriented work to confirm or refute the allegations and to address the concerns of the consent order. It was found that the metal finishing and manufacturing facility was responsible for the contamination and that remedial work was in order. Alternatives were developed and evaluated. The work completed to date indicates that the development of a new water supply, with the possible treatment of the ground water aquifer, is the most reasonable remedial alternative. Investigations are ongoing to determine the level of treatment, if any, required for the clean up of the ground water aquifer.

Lindorff, D.E. and Cartwright, K., "Ground Water Contamination: Problems and Remedial Actions", EGN 81, May 1977, Illinois State Geological Survey, Urbana, Illinois.

> Case histories of 116 ground-water contamination incidents reveal that remedial action is usually complex, time consuming, and expensive. Quick recognition of and response to an emergency involving ground water are essential to minimize the spread of contamination and make only minor remedial action necessary. However, the hydrogeologic setting and the pollution hazard at the specific locality should be assessed before corrective action is taken. The remedies most frequently used to renovate the subsurface environment include pumping and treating ground water, removing soil, draining away ground water via trenches, and removing the source of contamination. A combination of these techniques also has been used. Guidelines for strategies that consider the hydrogeologic framework and administrative structure of Illinois are presented. A committee or task force should define the scope of the problem and develop a formal procedure for dealing with various kinds of land and ground water pollution emergencies.

Lippitt, J., et al., "Worker Safety and Degree-of-Hazard Considerations on Remedial Action Costs", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1982, Hazardous Materials Control Research Institute, Silver Springs, Maryland, pp. 311-318.

In this paper, the authors review two projects undertaken to determine remedial action costs. The basic approach to developing costs was to identify the remedial action unit operations which may be combined to provide a remedial action plan. Component cost items were identified which contribute to each unit operation. By determining the cost associated with the component cost items, the total unit operation cost can be developed. A completed remedial action plan for a site can be evaluated by summing the costs of each of the remedial action unit operations involved.

Lochrane, T.G., "Ridding Groundwater of Hydrogen Sulfide -- Part I", Water and Sewage Works, Vol. 126, No. 2, Feb. 1979, pp. 48-50.

Hydrogen sulfide (H_2S) can be removed from water by aeration via gas transfer. The main function of the aerator is to speed up the reaction rate of H_2S releasing it to the atmosphere and reducing the overall chlorine need. As H_2S decreases in content, its ionic forms, HS^- and $S^=$ increase. If CO_2 is present in significant amounts it will be stripped faster than H_2S. This causes the pH to rise and decreases the removal efficiency. Ionized forms of H_2S, HS^- and $S^=$ can be removed by chlorination. Alkaline sulfide forms are not as simple to remove. Colloidal sulfur and polysulfides are converted to sulfates by adding sulfite. Thiosulfate canbe converted to sulfate by rechlorination.

Lord, A.E., Jr., "The Hydraulic Conductivity of Silicate Grouted Sands with Various Chemicals", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1983, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 175-178.

Grouting can be used to decrease permeability with special emphasis on stopping the flow of various hazardous chemicals moving within leachate or the ground water flow regime. Indeed, there is a very strong effort currently underway toward mitigating the effect of contamination of ground water, rivers and lakes by hazardous materials leaking from waste disposal sites. Cutoff walls of various types are being used to intercept the flow between the landfill site and the potentially pollutable water. Types of cutoff walls used in geotechnical engineering and heavy construction work, which are usually adopted to make seepage cutoff walls, are the following: cement grout type wall -- cement, cement/clay, cement/fly ash and cement/clay/fly ash; chemical grout type wall --

silicate, acrylamide and polyacrylamides, phenoplast, lignosulfite, aminoplast, some combinations of above, and new products (e.g., acrylate); slurry walls -- soil/bentonite backfilled trench, and geomembrane liner in a backfilled trench; and sheet pile walls -- interlocking steel sheets, tongue and groove precast concrete panels, and tongue and groove lumber.

The time dependent reaction of these cutoff wall materials with various chemicals is, in general, unknown. It is thought (usually without experimental justification) that a number of these materials are quite durable and impermeable to most chemical agents and environmental conditions. However, there has been very little work on the durability of these wall materials when in a possibly corrosive chemical environment. In retrospect, however, it was also thought that the clay materials commonly used at sanitary landfill sites for liners would be impervious to most chemicals. However, some very significant recent work showed this thinking to be quite false. In this work, it was shown that most organic solvents (acetone, xylene, methanol, etc.) will permeate readily through clay liners. The object of this study is to see if a similarly adverse behavior also occurs in chemically grouted walls, and the results of this study are presented.

Lu, J.C.S., Morrison, R.D. and Stearns, R.J., "Leachate Production and Management from Municipal Landfills: Summary and Assessment", Land Disposal: Municipal Solid Waste -- Proceedings of the Seventh Annual Research Symposium, 1981, U.S. Environmental Protection Agency, Cincinnati, Ohio, pp.1-17.

This report is a review, analysis, and evaluation of current literature and information on municipal landfill leachates. The overall objective is to provide documentation of practical information, current techniques, comparative costs, and additional research needs on the generation, composition, migration, control, and monitoring of leachates from municipal landfills. Due to the sizeable amount of information available on the subject matter only the conclusions are presented in this report.

Lundy, D.A. and Mahan, J.S., "Conceptual Designs and Cost Sensitivities of Fluid Recovery Systems for Containment of Plumes of Contaminated Groundwater", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1982, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 136-140.

Removal and treatment of contaminated fluids from wells or drains is the most commonly used method for controlling the movement of a plume of contaminated ground water. Other methods, such as fluid encapsulation within subsurface physical barriers and in-situ treatment or fixation, are being researched and applied, but those involving fluid removal probably will continue to be the most popular on the basis of their cost and reliability. This paper: (1) describes simple hydraulic models for making conceptual designs and cost estimates for recovery-well systems, and (2) examines the general sensitivities of recovery system costs to selected plume and aquifer characteristics. The costs presented are for simplified scenarios of contamination, which represent a foundation upon which more complex models can be built. Although the more complex models are increasingly being applied in the detailed design and evaluation of systems of recovery wells, there is and will continue to be a place for simpler mathematical models that can provide rough estimates of system discharge and number/size of recovery wells. The costs apply only to engineered structures and related services for a containment system, with other cost elements such as source removal, land purchase, legal services, etc., not included. Also, the paper is concerned not only with containment and treatment of contaminated ground water, but also with total cleanup of the site and the aquifer.

Lycott Environmental Research, Inc., "Final Report, Ground Water Resources Evaluation and Aquifer Protection Plan, Phase II", E-007-79, undated, Southbridge, Massachusetts.

Because Acton relies solely upon ground water for its water supply, it is extremely important for the Town to have a comprehensive inventory and evaluation of its ground water resources. This evaluation provides a basis for the Town's aquifer protection plan. Part of this evaluation is a ground water monitoring well network designed to provide an "early warning" system for the quality of water in Acton's aquifers. Analysis of water budgets for the Town's aquifer indicates that considerably more ground water is available for municipal development. The most favorable areas for additional water development appear to be the lower reaches of Fort Pond Brook, North Acton sites near Nashoba Brook and Butter Brook, west of Ice House Pond, and south of Mt. Hope Cemetery. The Sinking Pond aquifer is currently under study for rejuvenation (it is not currently being used for municipal drinking water supply because of organic chemical contamination), and this aquifer also may be able to sustain greater withdrawals once the contamination problems are solved. Modeling of nitrogen and sodium loading of the Town's aquifers will be completed as part of the aquifer protection plan. This plan will include recommendations for road-salting policies as well as other measures designed to protect the Town's aquifers.

Malone, P.G., Francingues, N.R. and Boa, J.A., Jr., "The Use of Grout Chemistry and Technology in the Containment of Hazardous Wastes", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1982, Hazardous Material Control Research Institute, Silver Spring, Maryland, pp. 220-223.

Uncontrolled hazardous waste sites include a wide variety of waste disposal locations where toxic wastes from manufacturing or mining activities have been discarded or dumped in a manner that poses a threat to human health and the environment. The potential pollutants vary from highly toxic organics to inorganic weathering products from mine spoils. In the superfund list of 160 problem sites, 134 sites involve significant pollution from toxic organics and 26 involved inorganic industrial wastes (such as battery or plating wastes), mine tailings or mine drainage or slag. The wastes at the disposal sites can be in tanks, lagoons, drummed storage or waste piles. In most cases, soil and ground water contamination from leakage or intentional discharge is already evident. Remedial actions at the sites usually take the form of removing waste to a safer location and/or developing a strategy for on-site containment by installing barriers to control waste movement or by immobilizing toxic constituents in place. In this paper, the authors discuss grouting technology and grouting equipment in remedial actions other than diversion of uncontaminated ground water. While grouts have long been used to stabilize soils for foundations or to produce barriers to control ground water movement in tunnelling or excavation, there are other aspects of grout chemistry that can be used to directly restrict chemical transport from waste materials.

Malone, P.G., Larson, R.J. and Meyers, T.E., "Stabilization/Solidification of Waste from Uncontrolled Disposal Sites", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1980, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 180-183.

Recent U.S. Environmental Protection Agency reports have estimated the number of unauthorized or uncontrolled hazardous waste disposal sites in the United States to be 2,000. AT most of these sites, the wastes are liquids and are held in 208-1 (55-gal) drums in open-air surface storage or stored in bulk in open impoundments. Cleanup of such sites involves identifying the wastes, attempting to treat or contain the wastes, and preparing the wastes to be shipped to a site for final disposal. In incidences where leakage has occurred, it is necessary to collect the contaminated soil also, for treatment or transportation to a secured landfill. The magnitude of the recontainerization or treatment effort is often so great that it involves building a waste disposal operation at major sites. The safety and security of cleanup and disposal operations can be improved if the wastes are converted into less reactive solid forms through processes termed stabilization/solidification. The purpose of this paper is to explore the possible application of stabilization/solidification technology to waste cleanup at dangerous abandoned or uncontrolled dump sites. Stabilization/solidification can be employed as a step to facilitate safer transportation and disposal.

Mathes, G.M., "Recovery of Spilled Petroleum Products from Fine Alluvium in the Mississippi River Aquifer", Proceedings of the Conference on Oil and Hazardous Material Spills: Prevention, Control, Cleanup, Recoery, Disposal, 1979, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 164-174.

This paper summarizes the results of Phases II and III of an on-going study aimed at identifying, locating, and dealing with the source(s) of gas odors experienced periodically since 1966 at many widespread locations in the city of Hartford, Illinois. The initial phase of this study identified multiple sources for the varied odors experienced. A major source for many of the odors was identified to be an underground accumulation of petroleum products trapped above the ground water beneath the city. Several house fires in the city have been attributed to the presence of air-gas mixtures. Two potential systems for providing high capacity depression wells and low capacity recovery wells were considered feasible. These may generally be described as follows:

(1) A single larger diameter well system with a 60 inch diameter hole and a 40 inch diameter screen where both the large capacity well and product recovery systems are housed in the same well. An estimated well depth on the order of 100 feet would be required to provide the necessary flow.

(2) A double well system where a different well is used to create a cone of depression than is used to recover the product. In this case a 28 inch diameter hole with 12 inch screen approximately 100 feet in depth would be required for the high capacity well and a 48 inch diameter hole with 30 inch screen to a depth of approximately 50 feet would be installed for recovery.

The first recovery system was installed in July, 1978 and the second system was installed in March, 1979. The first well was installed intersecting the largest of the three areas of product concentration. During the late summer, fall, and early winter, this well achieved production in the range of 500 to 1,400 gallons of product per day. Starting in late winter and early spring and extending through midsummer 1979, low production was obtained from both wells. This is attributed primarily to corresponding periods of rapid fluctuation in the aquifer due to precipitation and river level change. Monthly production figures and well hydrograph information were not available at the time of this paper to allow more detailed comparison. It has been reported that total monthly production has ranged from 6,000 to 30,000 gallons during the history of system operation. Through October, 1979, a total of approximately 192,000 gallons of product were recovered from the first well, and 40,000 gallons from the second well.

Matis, J.R., "Petroleum Contamination of Ground Water in Maryland", Ground Water, Vol. 9, No. 6, Nov.-Dec. 1971, pp. 57-61.

Petroleum contamination of ground water is a widespread problem that plagues many areas. Historical data collected in Maryland indicates that most counties in the state record cases of this contamination problem annually. Cases in the "hard-rock areas" west of the Fall Zone have the highest frequency of occurrence, in contrast to the Coastal Plain geologic province to the east. In both areas, the problems have been localized. It is difficult to handle petroleum contamination cases, and the legal implications are very complex. Many petroleum fuels do not deteriorate in the ground water system. Further, the identification of the specific petroleum products in ground water is generally not possible with present techniques. An investigation of a particular complaint can often be split into a preliminary phase and a detailed site investigations phase. Once a source of contamination is located, it must be stopped or removed. Since it is virtually impossible to remove the contamination from the ground water, legal and regulatory problems continue on for months or years after an original complaint.

Matthess, G., "In Situ Treatment of Arsenic Contaminated Groundwater", Studies in Environmental Science: Quality of Groundwater, Vol. 17, 1981, Elsevier Scientific Publishing Company, Amsterdam, The Netherlands, pp. 291-296.

Ground water in a sand and gravel aquifer was contaminated by arsenic compounds. The extent and the As concentration of the polluted ground water plume decreased from 1971 to 1975, whereas the content of free dissolved oxygen increased. High As concentrations (> 1 mg/l) occurred in ground water with typical characteristics of a "reduced" water with negative Eh values and high concentrations of dissolved iron (up to 140 mg/l in 1971). When plotted into an As stability field diagram, the higher values (> 1 mg As/l) coincided with the fields of trivalent As species, whereas the lower value (< 0.1 mg As/l) fitted to the fields of the pentavalent arsenic species. Therefore it was concluded that an improvement of the oxygen supply should accelerate the natural precipitation processes. By injection of 29,000 kg $KMnO_4$ into 17 wells and piezometers the soluble As (III) species were oxidized to As (V) species, which were precipitated as $FeAsO_4$ or $Mn_3(AsO_4)_2$ or co-precipitated with Mn- and Fe-hydroxides.

McBride, K.K., "Decontamination of Ground Water for Organic Chemicals: Selected Studies in New Jersey:, Proceedings of the Second National Symposium on Aquifer Restoration and Ground Water Monitoring, 1982, National Water Well Association, Worthington, Ohio, pp. 105-114.

Ground water contamination in New Jersey is a direct result of industrialization and population density. Over the past decade, government has responded to the problem by developing regulations governing all discharges to ground water. Contamination by synthetic organic chemicals is the most severe and widespread ground water problem, and has necessitated installation of monitoring and decontamination systems throughout the state. Hydrogeology, geography and contaminant-type affect design and monitoring wells and the final decontamination program. Sophisticated municipal wastewater treatment facilities have been used to treat contaminated ground water in industrialized areas, enabling comparatively inexpensive cleanup. In more rural settings, on-site systems using air-stripping or granular activated carbon have been successful. Spilled petroleum products are now pumped routinely from the ground using recovery wells or trenches. Recently, in-ground treatment of petroleum hydrocarbons has been accomplished using microorganisms. Overall, decontamination systems have repeatedly achieved 50 to 90 percent contaminant reduction. Contaminant levels in degraded aquifers are known to fluctuate in response to recharge events and the nature of the source. Nonetheless, marked decreases have been noted when the sources are removed. Aquifer restoration is a prolonged process requiring years to obtain a significant improvement.

McGarry, F.J. and LaMarre, B.L., "Proposed Cleanup of the Gilson Road Hazardous Waste Disposal Site, Nashua, New Hampshire", Proceedings of the National Conference on Management uf Uncontrolled Hazardous Waste Sites, 1982, Hazardous Materials Control Research Institute, Silver Springs, Maryland, pp. 291-294.

The Gilson Road Hazardous Waste Dump site is located in Nashua, New Hampshire, near the New Hampshire/Massachusetts State line. The site was developed as a sand borrow pit by the owners, with substantial quantities of sand having been removed over several years of operation. The sand excavation at many locations extended into the ground water table underlying the site. At some point in the late 1960s, the owner decided to discontinue the same mining operation and began the operation of an unapproved and illegal refuse dump with the apparent intent of filling the pit left by the sand mining. Household refuse and demolition materials were the initial components of the wastes dumped at the site. Eventually, chemical sludges and aqueous chemical wastes were also dumped there. The domestic trash and demolition material were usually buried while the sludges and liquid chemicals were disposed of in several ways: mixed with the trash and buried, placed in steel drums and either buried or stored on the surface, or dumped into a makeshift leaching field and allowed to percolate into the ground. It was estimated that the site was used for the disposal of hazardous wastes for approximately five years.

Cleanup activities began in 1980, as soon as legal access to the site could be obtained. During May and June of that year, 1,314 drums, which were accessible, were removed by a contractor and disposed of at approved secure landfills in the States of New York and Ohio. Immediately following removal of the drums, a ground water exploration and monitoring program was initiated to determine the magnitude and extent of the contamination. In July of 1981, an engineering report prepared by another consultant stated that there were high concentrations of heavy metals, volatile organics, and extractable organics in the ground water under the site. The metals and much of the extractable organics could be traced to the domestic refuse while the volatile organics likely originated from the makeshift leaching field used for the disposal of most of the aqueous wastes.

The concentration of organics, measured as total organic carbon, was found to be over 4,000 mg/l. Total metals concentrations, in the most contaminated portion of the plume, were in excess of 1,000 mg/l. Some of the major organic contaminants included methylene chloride, methyl ethyl ketone, toluene, benzene, chloroform, tetrahydrofuran, and acetone. The metals found at the site included iron, manganese, nickel, zinc, barium and arsenic. The primary remedial measure recommended by the initial consultant was the encapsulation of a 12.5 acre site with a slurry trench cut-off wall and an impermeable surface cap. For that portion of the ground water plume outside the containment wall, a treatment system would be installed which would intercept and treat the ground water. The treatment process would consist of air stripping, biological oxidation, and activated carbon adsorption. Chemical precipitation of the metal contaminants was considered to be an optional treatment step. Following cleanup of the aquifer outside the slurry wall, all further activities would be terminated and the site would be left with the slurry wall to permanently contain the 12.5 acres of contaminants.

McLin, S.G. and Tien, P.L., "Hydrogeologic Characterization of Seepage from Uranium Mill Tailings Impoundments in New Mexico", Proceedings of the Second National Symposium on Aquifer Restoration and Ground Water Monitoring, 1982, National Water Well Association, Worthington, Ohio, pp. 343-358.

Seepage of waste liquids into shallow outcroppings of an interbedded sandstone-shale sequence of the Upper Gallup Sandstone aquifer was examined in order to characterize the potential for extensive off-site subsurface contaminant migration. These waste liquids are from a uranium mining and acid leach milling operation located near Gallup, New Mexico. Preliminary water balance studies from evaporation holding ponds indicated that as much as 80,000 gallons of rafinnate liquid containing up to 60,000 mg/l TDS had entered the aquifer each day during an 18 month period. Ground level and photogeologic mapping efforts depicted the presence of a major regional subsurface fracture trace adjacent to the tailings disposal site. Surface electrical resistivity, borehole geophysical and core fractographic analyses confirmed the presence of subsurface fractures, in addition to extensive contaminant movement. Formation hydraulic testing indicated at least some anisotrophy in hydraulic conductivity that may be unrelated to rock fracturing. Approximately 200 monitoring wells were eventually utilized in mapping a subsurface contaminant plume nearly 1.5 miles long and 0.75 miles wide. A system of pumping wells was designed and installed in order to partially control further extensive plume movement. Monitoring efforts are continuing in order to assess the feasibility of total containment on a long-term basis.

McMillion, L.G., "Ground Water Reclamation by Selective Pumping", Society of Mining Engineers, AIME - Transactions, Vol. 250, Mar. 1971, pp. 11-15.

A field project to develop and demonstrate a method for alleviating problems of highly mineralized ground water where they occur as isolated zones or pockets in fresh-water aquifers was conducted in the Ogallala aquifer of eastern New Mexico. Removal of contaminated water is by a large-capacity well and the pumped poor-quality water is used locally for secondary recovery of oil. Benefits of the operation are threefold in that the aquifer is being reclaimed for future fresh-water production, contaminated water is being used beneficially, and fresh water which otherwise would have been used for waterflooding is available for other purposes. Ground water quality in the site has improved markedly after two years of operation.

Michalovic, J.G., et al., "System for Applying Powdered Gelling Agents to Spilled Hazardous Materials", EPA-600/2-78-145, July 1978, U.S. Environmental Protection Agency, Cincinnati, Ohio.

Research had been conducted to develop a blended material that would optimally immobilize a wide range of liquid chemicals detrimental to the environment. The product of this research was Multipurpose Gelling Agent (MGA), a blend of four polymers and an inorganic powder. When applied to a chemical spill, MGA turns the hazardous liquid into a gelatinous mass which can be easily removed by shovel or other mechanical means. The MGA research program has also included design, fabrication, testing, and demonstration of a mobile, self-powered, mechanical system for dispensing powdered MGA to spill target areas in a safe and effective manner. A prototype of the Mobile Dispensing System (MDS) was constructed and tested. The MDS unit incorporates an auger-fed pneumatic conveyor system and a trailer that can be towed to remote spill sites. After initial testing to determine the MGA range and dispersal pattern, the MDS unit was tested against both small- and large-scale simulated spills.

Mido, K.W., "An Economical Approach to Determining the Extent of Ground Water Contamination and Formulation of a Contaminant Removal Plan", Ground Water, Vol. 19, No. 1, Jan.-Feb. 1981, pp. 41-47.

If past ground water movement in the vicinity of contamination could be shown pictorially, determination of the extent of contamination would be facilitated significantly. Furthermore, if pictorial representation of future ground water movement under presumed conditions reflecting alternative plans of contaminant removal or containment could be provided rapidly, an effective plan could be developed speedily and thus economically. A flow path and arrival time plot, which is developed through the use of a flow system kinematics mathematical model, provides such visualization of ground water movement. Contrary to the popular notion that the kinematics model requires much more geohydrologic data than the finite difference or element models, it was found that meaningful kinematics models could be developed based on relatively limited data. Presented in this paper are: a brief description of the development of flow path and arrival time plots, information obtainable from such plots, an example of the use of the plots in determining the extent of contamination of ground water, and an example of the use of the plots in formulating a contaminant removal plan.

Miller, D.G., Jr., "In Situ Treatment Alternatives and Site Assessment", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1983, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 221-225.

Remedial action alternatives at sites contaminated by waste management practices should be evaluated on the basis of technical feasibility, cost and long term effectiveness. One set of alternatives, in situ treatment, is attractive because it can result in minimal exposure and eliminate off-site transportation of the waste. In situ treatment, however, is questionable with regard to physical and chemical uniformity of treatment and long term chemical stability. Experience with numerous projects has demonstrated the need for adequate physical and chemical characterization of the system to be treated. In situ treatment as considered in this paper is restricted to the introduction of chemicals into the subsurface, rendering contaminants less hazardous to the environment. The process has also been referred to as neutralization/detoxification or detoxification and stabilization. In this paper, the author addresses in situ treatment of inorganic contaminants, primarily heavy metals, although similar concepts and physical characteristic concerns may be applicable to in situ biodegradation. In spite of demonstrations of physical feasibility by full scale tests, current use is limited because of the concerns of overall reliability and costs associated with demonstration and implementation. An understanding of these concerns is necessary to properly evaluate in situ treatment as an alternative.

Millet, R.A. and Perez, J.Y., "Current USA Practice: Slurry Wall Specifications", Journal of the Geotechnical Engineering Division - ASCE, Vol. 107, No. GT8, Aug. 1981, pp. 1041-1056.

To establish diaphragm and cutoff slurry wall design criteria and, thus, specifications, the designer must clearly establish the objectives or end results that are to be obtained. This paper considers the critical design criteria and the resulting specifications for both slurry trench diaphragm walls and cutoff walls. Diaphragm and cutoff walls are initiated with a common process. This process is the excavation of a narrow trench without the use of significant lateral support other than that provided by a bentonite-water slurry which is pumped into the trench so that the slurry level is maintained at or near the top of the trench throughout the excavation process. In the diaphragm wall process, after completion of a segment of excavated trench, either cast-in-place concrete (tremie process) or precast panels are used to displace the stabilizing mud and construct a load-bearing wall (vertical and lateral). There are two types of slurry cut-off walls: (1) soil-bentonite; and (2) cement-bentonite. In the soil-bentonite cutoff process, the bentonite slurry is displaced by a soil-bentonite mixture similar in consistency to high slump concrete. The soil backfill forms a low permeability highly plastic cutoff wall. In the cement-bentonite cutoff process, cement is added to a fully hydrated bentonite-water slurry. The cement-bentonite-water slurry is then used to both stabilize the slurry wall during excavation, and upon setting of the cement, for the permanent cutoff wall itself.

The critical design criteria for the two types of slurry walls are: (1) diaphragm walls -- structural strength and integrity, permanence, and permeability; and (2) cutoff walls -- permeability, deformability, and permanence. End-result (performance-guaranteed) specifications are acceptable if the owner, engineer, and contractor truly understand and can agree on what end results are to be obtained.

Molsather, L.R. and Barr, K.D., "Retrofit Leachate Collection System for an Existing Landfill", Proceedings of the Second National Symposium on Aquifer Restoration and Ground Water Monitoring, 1982, National Water Well Association, Worthington, Ohio, pp. 316-322.

> This paper describes methods and special considerations involved in design and construction of a leachate collection system installed adjacent to an existing landfill site. While the authors use a recent project to illustrate the design methods employed and to discuss certain site-related problems, they are of the opinion that the methods used and the solutions to certain problems are generally applicable and should be of value in relation to planning and installation of facilities on other sites. Basic modeling techniques were employed in evaluating watershed yield, in predicting variations in seepage collection rate during normal operating conditions and construction and in evaluating the effects of the collection system on the site. Practical items discussed in the paper include the methods considered for collecting toe seeps, construction procedures used for installation of facilities in peat and other unstable soils, selection of construction materials and certain safety considerations related to construction adjacent to an existing landfill site.

Muller, B.W., Brodd, A.R. and Leo, J., "Picillo Farm, Coventry, Rhode Island: A Superfund and State Fund Cleanup Case History", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1982, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 268-273.

> The cleanup of unauthorized hazardous waste sites presents varied operational and environmental problems. In this paper, the authors provide insight into the chronology, operational techniques, air monitoring aspects, water monitoring and problem areas associated with the abatement of such a site situated in Rhode Island. Field and off-site disposal analyses proved to be a problem in terms of turnaround time and procedural techniques. Particular attention must be paid to the analytical requirements so that they: (1) keep pace with excavation efforts, and (2) provide the required disposal analyses in a timely fashion. One of the primary operational constraints involves reducing the risk of injury and adverse health effects to personnel working on site and the surrounding population. A key aspect of this risk reduction strategy involved monitoring the atmosphere to assess the degree of hazard in the following areas: explosion, oxygen deficiency and exposure to contaminants. Funding of a project of this scope must around for the significant unknown factors associated with hazardous waste cleanup, i.e., what is the amount and type of material to be excavated and disposed of? The generation of contaminated soil poses a significant disposal problem. Successful efforts were made to limit this problem in Phase II and III in

terms of the smaller amount of generated contaminated soil. However, at some point, a disposal or treatment option must be chosen to deal with this problem. Finally, and most importantly, all activities should be closely coordinated with any citizens organization or affected group that deals with the issues of hazardous wastes. An informed citizenry can aid procurement of funding and maintain the necessary interest in the issue that influences governmental decisions. Working closely with such organizations promotes cleanup effects, maintains good press relations and may accelerate completion of the job.

Muller-Kirchenbauer, H., Freidrich, W. and Hass, H., "Development of Containment Techniques and Materials Resistant to Groundwater Contaminating Chemicals", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1983, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 169-174.

In 1970, approximately 50,000 disposal sites were registered in the Federal Republic of Germany. Two percent of these seem to contain hazardous wastes and need appropriate treatment so that the ground water and the surroundings shall not be affected. Additionally, there are further unregistered intrusions from earlier times and from World War II such as bombed factories and oil or chemical storage. Clearly the best way to correct pollution at these sites is to dig them up and to refill the pits with clean material. However, in the case of very deep contamination or of intensively settled surroundings, the dig and refill procedure is neither technically nor economically possible. This has resulted in an intense search for alternative solutions in recent years. Progress has been made with encapsulation techniques. Although this concept can be successfully used, there are many special conditions that have to be considered; these are discussed in this paper.

Mutch, R.D., Jr., Daigler, J. and Clarke, J.H., "Clean-up of Shope's Landfill, Girard, PA", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1983, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 296-300.

Refuse and industrial waste from the Lord Corporation of Erie, Pennsylvania was dumped on the property of a maintenance department employee from the late 1950's to 1979. The landfill was closed in 1979 after having blanketed an area of about 4.5 acres. Very evident leachate problems at the landfill prompted the Pennsylvania Department of Environmental Resources to initiate discussions with the employee and the Lord Corporation. Lord Corporation, recognizing its role as generator of virtually all of the wastes in the landfill, accepted responsibility for investigation and remediation of the landfill. The selected remedial program encompasses a number of individual remedial components. The principle objective of the plan is the virtual elimination of recharge to the landfill, which is accomplished by the combination of the impermeable cap and the upgradient cut-off wall. The plan's major components are: (1) removal and off-site disposal of drums from the landfill surface and those encountered in regrading of the fill's side-slopes; (2) removal of standing pools of leachate and site drainage facilities; (3) surface water diversion and site drainage facilities; (4) an impermeable final cover (cap); (5) an upgradient (southern) cut-off wall; and (6) a short- and long-term monitoring program.

Myers, V.B., Domenico, D.D. and Hartsfield, B., "Remedial Activities at Florida's Uncontrolled Hazardous Waste Sites", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1982, Hazardous Materials Control Research Institute, Silver Springs, Maryland, pp. 295-298.

Florida's water resources are not limited to its expansive 1200 mile coast line and over 7000 freshwater lakes. It is also blessed with an abundant supply of ground water. The Floridan Aquifer underlies the majority of peninsular Florida and supplies most of the potable water needs of north and central Florida. The Floridan Aquifer is at the surface in many areas of central Florida. In coastal areas where the Floridan Aquifer is saline, surface aquifers are used for potable drinking water. The majority of the state has very pervious soils which allow for rapid transport of contaminants to the shallow surface aquifers; hence the ground water is extremely vulnerable to contamination. Toxic materials are finding their way into ground water from various sources: hazardous waste dumps, waste lagoons and pits, sanitary landfills, accidental spills, mining operations, and storm water runoff. A recent assessment funded by the USEPA showed over 70% of Florida industries using unlined impoundments for waste disposal. This is particularly alarming when 98% of the 6000 impoundments were located over useable drinking water aquifers. Florida's prominent position on EPA's Interim Priority List of uncontrolled hazardous waste sites is due, in part, to the susceptibility of the state's ground water to contamination.

This paper presents overviews of the preliminary remedial action planning and monitoring activities at seven of Florida's 16 Superfund sites. Included are discussions concerning a manufacturer of electrical solderless terminals, an inactive wood treatment (creosote) facility, a landfill, hydrocarbon spills at an airport, a drum recycling facility, a battery salvage company, and a series of oil pits.

Nebgen, J.W., et al., "Treatment of Acid Mine Drainage by the Alumina-Lime-Soda Process", EPA/600/2-76-206, Sept. 1976, U.S. Environmental Protection Agency, Cincinnati, Ohio.

The alumina-lime-soda process is a chemical desalination process for waters in which the principal sources of salinity are sulfate salts and has been field tested at the Commonwealth of Pennsylvania's Acid Mine Drainage Research Facility, Hollywood, Pennsylvania, as a method to recover potable water from acid mine drainage. The alumina-lime-soda process involves two treatment stages. Raw water is reacted with sodium aluminate and lime in the first stage to precipitate dissolved sulfate as calcium sulfoaluminate. In the second stage, the alkaline water (pH = 12.0) recovered from the first stage is carbonated to precipitate excess hardness. Following carbonation, product water meets USPHS specifications for drinking water. Alumina-lime-soda process economics are influenced most by the cost of sodium aluminate.

Neely, N.S., et al., "Survey of On-Going and Completed Remedial Action Projects", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1980, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 125-130.

The Resource Conservation and Recovery Act (P.L. 94-580) was promulgated in 1976 to control the ultimate disposal of solid and hazardous waste. Beginning in 1980, proper disposal and removal of hazardous substances became a major concern of the U.S. Environmental Protection Agency (EPA), other government agencies and private citizens. In an effort to determine the type and effectiveness of past corrective technology applied at uncontrolled sites, a nationwide survey of on-going and completed remedial action projects was implemented. The purpose of the survey was to provide examples of applied remedial action technologies to government officials, private facility owners/operators, and state regulators. Examples provided in the form of case histories identified problems, effectiveness, and cost related to implementing remedial action at uncontrolled hazardous waste disposal sites.

Remedial measures usually consisted of containment and/or removal of the hazardous wastes. The primary goal has been the prevention of further contamination of the environment rather than complete cleanup. Complete environmental cleanup of ground water or surface water generally requires higher technology, additional money and additional time. Therefore, a responsible party with sufficient funds and expertise must be located for complete cleanup to occur. In most cases sufficient funds have not been available for effective remedial action. It is difficult for the states and local governments to provide sufficient money for total cleanup, since any one site may require millions of dollars to correct its problems.

Based on the case studies and survey, the present state-of-the-art in applied remedial action does not look favorable when one considers that 46% of the time the applied remedial action was ineffective and only a portion of all uncontrolled sites have received some form of remedial action. In addition, remedial action applied at a site experiencing problems was only totally effective 16% of the time. It is emphasized that the percentage numbers are based on many assumptions, one of which is the subjective opinions of personnel interviewed. However, the numbers are an accurate representation of the tendency of applied remedial action. For example, it is apparent that there is a need for additional applications of corrective measures and that the state-of-the-art of remedial action needs improvement.

Neely, N.S., et al., "Remedial Actions at Hazardous Waste Sites: Survey and Case Studies", EPA 430/9-81-05, Jan. 1981, U.S. Environmental Protection Agency, Washington, D.C.

During the summer of 1980, a nationwide survey was conducted to determine the status of remedial actions applied at uncontrolled hazardous waste disposal sites. Over 130 individuals were contacted to obtain information on such remedial action projects. A total of 169 sites were subsequently identified as having been subject to corrective measures. Remedial actions were found to have been implemented at many kinds of hazardous waste disposal facilities including drum storage areas, incinerators, and injection wells, but most frequently landfill/dumps and surface impoundments. At the sites receiving such remedial actions, ground water was found to be the most commonly affected media, followed closely by surface water. Although several types of remedial measures were identified, remedial activities usually consisted of containment and/or removal of the hazardous wastes. Sufficient money was often not available for complete environmental cleanup (e.g., extraction and treatment). The survey determined that a lack of sufficient funds and/or selection of improper technologies were responsible for remedial actions having been applied effectively at only a portion of the uncontrolled hazardous waste disposal sites. Where they had been applied, remedial actions were found to be completely effective only 16 percent of the time. Nine sites were studied in detail to document typical pollution problems and remedial actions at uncontrolled hazardous waste disposal sites. Of these nine sites, remedial actions were completely effective at two and only partially effective at the other seven. Technologies employed at these nine sites included (1) containment, (2) removal of waste for incineration or secure burial, (3) institution of surface water controls, and (4) institution of ground water controls.

Niemela, V.E., Childs, K.A. and Rivoche, G.B., "Leachate Treatment and Mathematical Modelling of Pollutant Migration from Landfills and Contaminated Sites", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1982, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 437-441.

> Pollution of both ground and surface water by toxic contaminants migrating from dangerous hazardous waste storage and disposal sites, and particularly from areas of land contaminated by various industrial activities, is a widespread problem. In this paper, the authors review and attempt to assess the current remedial technologies used in NATO countries, with special emphasis on control and treatment of leachate and of contaminated ground water. This overview includes the engineering design of various cut-off barriers, grout curtains, clay fill trenches, etc. required to contain contamination, but does not include an analysis of the physical and chemical effectiveness of such barriers. The focus of this paper is also on mathematical modelling, a proven tool in site-specific situations but perhaps a more controversial one from the viewpoint of general applicability.

Nightingale, H.I. and Bianchi, W.C., "Ground Water Chemical Quality Management by Artificial Recharge", Ground Water, Vol. 15, No. 1, Jan.-Feb. 1977, pp. 15-21.

> The effectiveness of the Leaky Acres Recharge Facility in Fresno, California, for improving the regional ground water quality was studied as 65,815,000 m^3 of high-quality surface water was recharged from 1971 through 1975. Observation wells at the facility showed some variability in chemical parameters associated with each recharge period. The long-term decrease in salinity could be described by a power law decay curve fitted by regression analysis. Recharge of Leaky Acres had noticeably decreased the ground water salinity for a distance of up to 1.6 km. in the direction of the regional ground water movement.

Ohneck, R.J., "Restoration of a Contaminated Aquifer Following an Accidental Spill of Organic Chemicals", Proceedings of the Second National Symposium on Aquifer Restoration and Ground Water Monitoring, 1982, National Water Well Association, Worthington, Ohio, pp. 339-342.

> Current regulations prescribe efforts to be implemented to contain, monitor and clean up contaminated ground water. Accidental spills are one source of ground water contamination that is apparent and can be abated when actions are quickly and efficiently administered. New methods for containment, recovery and treatment of spills affecting ground water are being developed to satisfy these criteria. This paper contains a case history of a situation where a spill of 100,000 gallons of organic chemicals of various

makeup contaminated a ground water system. The spill was responded to immediately, assessed, contained, recovered and treated on site. As a result of these efforts, the aquifer was restored to a usable condition. Innovative techniques were used, including hydraulic containment of the ground water by subsurface injection and recovery systems, mobile on-site treatment systems and in situ biological treatment of soil and ground water.

Opitz, B.E., Martin, W.J. and Sherwood, D.R., "Gelatinous Soil Barrier for Reducing Contaminant Emissions at Waste Disposal Sites", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1982, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 198-202.

The disposal of hazardous wastes, such as sanitary landfill leachate, chemical waste, or radioactive waste, is an increasing problem. Current practices call for waste disposal in earthen pits or repositories. However, these waste contaminants may eventually migrate so that potentially hazardous elements could be transported to the biosphere. Thus, reducing the transport of chemicals from waste disposal sites poses an immediate challenge.

Under sponsorship of the Department of Energy's Uranium Mill Tailings Remedial Action Program (UMTRAP), Pacific Northwest Laboratories (PNL) has investigated the use of engineered barriers for use as liners and covers for waste containment. A comparison of clay-soil mixtures and a gelatinous soil additive was performed to evaluate their use as a cover in reducing the escape of radioactive radon gas from abandoned uranium mill tailings piles. In addition, permeability measurements were performed to examine and compare the ability of gelatinous materials to reduce leachate movement and the migration of contaminants such as trace or heavy metals. The results of these studies led to the development of a low permeable, multilayer earthen barrier for effectively reducing contaminant emissions from waste disposal sites.

Osiensky, J.L. and Williams, R.E., "Ground Water Pump-Back System for a Uranium Tailings Disposal Site", Proceedings of the Second National Symposium on Aquifer REstoration and Ground Water Monitoring, 1982, National Water Well Association, Worthington, Ohio, pp. 30-37.

Seepage from unlined disposal ponds that contain uranium mill wastes has contaminated the ground water at several sites in the United States. Ground water "pump-back" systems are one alternative for controlling the migration of seepage at these sites. The installation and operation of an effective and efficient ground water pump-back system are dependent upon the adequate delineation of the site hydrogeology and the geometry of the seepage plume(s). Adequate delineation of the hydrostratigraphy and identification of the hydrostratigraphic unit(s) through which seepage is migrating is necessary to determine the proper locations, completion schedules and pumping rates for the pump-back wells. Disposal of mill wastes at one waste disposal site began in 1957. In 1980, a contaminated seep was discovered approximately 518 meters (1,700 feet) north of Tailings Pond No. 1. Hydrogeologic exploration at the site revealed an alluvium-filled paleo-channel. Precise delineation of the channel and the hydraulic properties of the alluvium were prerequisite to the implementation of a withdrawal scheme. A ground water pump-back system recently has been installed at the site to dewater the alluvium in the paleo-channel and return the contaminated water to a new tailings disposal facility designed so as not to leak.

Padar, F.V., "Identification and Control of Organic Chemicals in Sole Source Aquifers on Long Island, New York", Proceedings of the Conference on Oil and Hazardous Material Spills: Prevention, Control, Cleanup, Recovery, Disposal, 1979, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 140-150.

Widespread contamination of ground water, the sole source of drinking water for 2.8 million people on Long Island, New York, by industrial solvent discharges and underground gasoline spills has created unique public health and environmental protection problems. Ground water contamination by leaking of buried gasoline storage tanks has presented a series of technical problems including determining the spatial extent of aquifer contamination, notably from benzene, marshaling the best available technology for clean-up of spills, disposition of contaminated ground water pumped from recovery wells, development of field equipment for treatment of contaminated water, and determination of an appropriate standard or end point for restoration of ground water quality.

Paige, S.F., et al., "Preliminary Design and Cost Estimates for Remedial Actions at Hazardous Waste Disposal Sites", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1980, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 202-207.

Uncontrolled hazardous waste disposal sites produce adverse effects on public health and the environment as a result of the migration of hazardous waste constituents to off-site locations. Remedial actions are implemented as a means of mitigating the adverse effects produced by these sites. Before a final decision is made concerning the type of remedial actions to be implemented at a site, there should be discussions and investigations regarding the nature of the problem at the site and the efficacy of candidate remedial action techniques. At some point during this decision-making process, it will be necessary to develop preliminary designs and cost estimates for the remedial action programs being considered. In preparing the preliminary design, the investigator has to identify each of the steps that will be involved in implementation of the remedial action. Therefore, the exercise will provide officials a realistic picture of the extent of activity required by the remedial action. The cost estimate may provide useful input to the decision-making process. From a regulatory perspective it will also help to assess amount of damages that should be included in enforcement actions against responsible parties.

Parmele, C.S. and Allen, R.D., "Activated Carbon Adsorption with Nondestructive Regeneration -- An Economical Aquifer Restoration Technology", Proceedings of the Second National Symposium on Aquifer Restoration and Ground Water Monitoring, 1982, National Water Well Association, Worthington, Ohio, pp. 99-104.

The use of activated carbon adsorption as an aquifer restoration technology has drawn widespread consideration. Often, critics point to the high cost of carbon replacement and/or thermal regeneration to justify claims of unreasonable cost. This is not the first time that the incentive to develop cheaper ways to regenerate activated carbon has been identified. IT Enviroscience has demonstrated that for process wastewaters nondestructive regeneration can be accomplished for one-third of the operating cost of thermal regeneration. IT Enviroscience believes that the economic incentive exists to evaluate activated carbon adsorption with nondestructive regeneration by itself and in conjunction with other technologies as solutions to the ground water contamination problem. This paper describes nondestructive regeneration techniques and applications. It shows how cost savings over other ground water treatment systems can be achieved.

Parmele, C.S., Alperin, E.S. and Exner, J.H., "Nondestructive Regeneration of Activated Carbon -- A Viable Chemical Engineering Technology", Paper presented at the American Institute of Chemical Engineers Annual Meeting, Nov. 1981, New Orleans, Louisiana.

Solvent regeneration and steam regeneration were used to nondestructively regenerate activated carbon in a pilot plant study using six-inch adsorption columns. For solvent regeneration the pilot plant was operated on actual wastewater and also with wastewater spiked with a strong phenol $>1\%$. In this demonstration, the study demonstrated that a stable working capacity of 0.15 phenol/lb carbon was established and maintained during 17 adsorption/desorption cycles. An effluent concentration of <1 mg/l was routinely achieved. Distillation of the acetone regenerant produced a product that could be reused in the process. Operating cost (exclusing of capital and labor) were $0.02/lb carbon regenerated while the value of the recovered phenol gave a credit of \$0.03/lb carbon. Using a steam regeneration process in order to remove volatile organics such as ethylene dichloride (EDC) from process wastewater showed that a stable working capacity of 0.40 lb EDC/lb carbon was established with steam regeneration over 9 adsorption-desorption cycles, and that the EDC effluent concentration was $\leq$ 5 mg/l. Since the EDC feed concentration was 2000-7000 mg/l, EDC removal was > 99.97%. Nondestructive regeneration processes will allow greater utilization of carbon adsorption by providing in-situ regenerator, adsorbate recovery and lower cost regeneration technology.

Parry, G.D.R., Bell, R.M. and Jones, A.K., "Degraded and Contaminated Land Reuse-Covering Systems", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1982, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 448-450.

As a result of proposals made by the United Kingdom in 1980, a NATO/CCMS pilot study on contaminated land has been established. A range of study areas and subjects for information exchange have been selected. Study Area C in this project has a UK lead, and will examine systems designed to prevent the migration of contaminants vertically or laterally or to prevent the ingress of surface or ground water into contaminated sites. In this paper, the authors discuss the desirable properties of covering systems and by example describe their use in the UK.

Pastrovich, T.L., et al., "Protection of Groundwater from Oil Pollution", Report No. 3/79, Apr. 1979, CONCAWE, The Hague, Netherlands.

Problems arising from ground water pollution by oil have gradually emerged during the past few years as an important area of concern for those involved in water resource exploitation and management. The most critical use of ground water is for domestic use. But in this case consumption of contaminated water in most cases poses little hazard to health because people and animals find the water unpalatable at levels of contamination far below those that would be harmful. The lower limit of detectability depends on the type of petroleum product and on the sensitivity of the person concerned. However, the rather low limits proposed by various authorities suggest that it is advisable to give recommendations and guidance on how to protect the subsoil drinking water resources from hydrocarbons and their biodegradation products. The "Oil Spill Manual" published by CONCAWE in August 1974 deals with the recovery of oil spilled onto the soil and onto surface waters. The main factors to be taken into account before implementing any remedial measures are also discussed in detail.

Pearson, F.H. and Nesbitt, J.B., "Combined Treatment of Municipal Wastewater and Acid Mine Drainage", Research Publication No. 73, undated, Institute for Research on Land and Water Resources, Pennsylvania State University, State Park, Pennsylvania.

Acid mine drainage (AMD), a serious water pollutant in many states, may be an economical source of ferrous iron for the chemical coagulation of municipal wastewater. AMD would then be neutralized by the alkalinity in wastewater. Samples of AMD and raw wastewater were collected from sites in Pennsylvania where AMD was found close to a wastewater treatment plant. The samples were mixed in varying ratios, then processed at controlled pH in a laboratory scale treatment plant that provided flocculation and sedimentation. The optimal pH was 8 for a maximum reduction in phosphorus, ferrous iron, and turbidity. At pH 8 the median reduction in total phosphorous was 95 percent when the molar ratio of ferrous iron to total phosphorous was 2. Ferrous iron was almost completely removed at pH 8. A cost analysis is given for the maximum distance for which it is economical to pump AMD for combined treatment with wastewater.

Pease, R.W., Menke, J.L. and Welks, K.E., "Mangement of Abandoned Site Cleanups: Wade Property, Chester, Pennsylvania", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1980, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 147-151.

In this paper, the authors describe the conditions at an illegal hazardous waste site in Chester, Pennsylvania and the steps taken for their resolution. Several of the "how to" aspects of the planning and management of an abandoned site cleanup are illustrated in the context of the Chester project. The site, known as the Wade Property, is an approximately three-acre parcel bounded by the Delaware River, the Commodore Barry Bridge, the Philadelphia Electric Company's deactivated gas storage tanks, and a railroad right-of-way. Historically, drums of wastes at the site were emptied either directly onto the ground or into trenches; this discharge has severely contaminated the soil at several locations. A fire occurred on the site in February, 1978 causing many of the stockpiled wastes to be destroyed. Large piles of debris containing exploded drums, building materials, tires, shredded rubber, and chemically contaminated earth litter the property. Approximately 150,000 gallons of waste chemicals remained after the fire; most of the material was contained in 2,500 55-gallon drums located inside fire-damaged buildings, although a large portion was stored in five bulk tankers in the front lot. The Pennsylvania Department of Environmental Resources (DER), through the aid of a contractor, was involved in the development and implementation of environmentally acceptable and cost-effective solutions to the problems of hazardous waste disposal and pollution abatement associated with the Wade site. This paper describes these solutions.

Pendrell, D.J. and Zeltinger, J.M., "Contaminated Ground-Water Containment/Treatment System: Northwest Boundary, Rocky Mountain Arsenal, Colorado", Proceedings of the Third National Symposium on Aquifer Restoration and Ground Water Monitoring, 1983, National Water Well Association, Worthington, Ohio, pp. 453-461.

The Rocky Mountain Arsenal was constructed by the Army just northeast of Denver, Colorado, in 1942 to manufacture mustard gas, incendiary bombs and other miscellaneous munitions. Following World War II the plant was leased to private industry for the manufacture of insecticides and herbicides. In the early 1950s the Army constructed an additional plant to manufacture nerve gas. Liquid chemical wastes from all of these operations were discharged into unlined basins, resulting in contamination of a shallow aquifer. A bentonite slurry-filled cutoff trench and a ground water treatment plant were installed at the north boundary of the arsenal in 1981. The system is successfully preventing migration of a plume of contaminated ground water off the arsenal to the north. A second plume is migrating northwesterly off the arsenal at the northwest boundary. Recent investigations have confirmed that the most feasible method to stop migration of the plume is a combined hydraulic-bentonite slurry trench barrier with a treatment plant. This barrier will consist of 11 withdrawal wells spaced 100 feet apart and a bentonite slurry-filled trench 1,300 feet long. The cutoff trench is required in a thinly saturated area of the shallow aquifer. The water pumped from the withdrawal wells will be treated in carbon columns and then injected back into the aquifer through a line of recharge wells located 600 feet downgradient from the hydraulic-bentonite slurry trench. The recharge line is necessary to establish reversal of the ground water hydraulic gradient and to assure no disruption in the quantity of ground water flow off the arsenal. The paper briefly discusses the north boundary system, but concentrates primarily on the recent study at the northwest boundary, including contaminants, aquifer analysis and design of the northwest boundary containment/treatment system.

Pennington, D., "Retardation Factors in Aquifer Decontamination of Organics", Proceedings of the Second National Symposium on Aquifer Restoration and Ground Water Monitoring, 1982, National Water Well Association, Worthington, Ohio, pp. 1-5.

Movement of low-molecular weight halogenated organics in aquifer systems presents several problems for the investigation of contaminant control and aquifer restoration. Some of these organics are not appreciably absorbed in soils and move readily through aquifers. In contrast, other organics are relatively immobile. A measure of mobility of the organics is the retardation factor (ratio of the velocity of water flow to velocity of contaminant in aquifers). Retardation factors are listed for various organics including chloroform, 1,1,1-trichloroethane and chlorobenzenes. Because of retardation factors, dispersion and dilution processes will have different effects on selected organics and can result in variations of concentration of organics in the leachate plume. Therefore, the retardation factors can have a significant influence on abatement plans. Containment of some contaminants may be insignificant when an abatement plan assumes equal rates of movement of contaminants. Also, retardation factors have a significant effect on the calculation of the rate of flow of a leachate front and areal extent of the leachate plume. Case histories are utilized as examples of the significance of retardation factors.

Penrose, R.G. and Holubec, I., "Laboratory Study of Self-Sealing Limestone Plugs for Mine Openings", Sept. 1973, NUS Corporation, Pittsburgh, Pennsyvlania.

Laboratory studies of self-sealing limestone plugs for mine openings were conducted to determine the optimum limestone material for such a treatment and sealant technique. Experimental results indicated that permeability, compressibility and strength of a limestone plug are primarily a function of the particle size distribution and density. Plug performance was most effective with high limestone placement density and smaller gradation of stone. Ferric waters were controlled most effectively. Additive effects were less significant throughout the tests.

Pye, V.I., Patrick, R. and Quarles, J., "Remedial Action and the Rehabilitation of Aquifers", Groundwater Contamination in the United States, 1st ed., University of Pennsylvania Press, Philadelphia, 1983, pp. 182-188.

This chapter of the book deals with a state-of-the-art review of the various aquifer restoration techniques. The most recent literature is reviewed for a number of topics including: in-situ remedial alternatives; conventional alternatives of withdrawal, treatment and final disposal; and treatment options. Also included are a series of figures schematically depicting the various treatment technologies.

Quan, W., "The Effective Use of Resource Recovery in the Cleanup of Uncontrolled Hazardous Waste Sites - Based on the California Experience", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1981, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 380-386.

One of the most important environmental concerns today is the location and management of uncontrolled hazardous waste sites. Very often the most expeditious way of cleaning up a site is removal of the waste for disposal at a permitted hazardous waste disposal site; this is not necessarily the most prudent way of solving the problem. Furthermore, California and the rest of the country are now experiencing increasing difficulty in siting new hazardous waste disposal sites. According to a 1980 EPA contracted study of nine uncontrolled hazardous waste sites in the United States, the remedial action technologies usually employed were onsite containment and surface/ground water monitoring, and waste removal of landfill burial or incineration at permitted facilities. Only once was resource recovery employed as part of a cleanup program. In the long run, even though it usually takes a longer period of time for a site to be cleaned up through resource recovery, it is probably, in many instances, the soundest solution. Sometimes it may take a joint cooperative effort of everybody concerned for resource recovery to work. Furthermore, landfill disposal and/or on-site containment measures may be only temporary solutions. Four California case studies of uncontrolled hazardous waste sites are presented. For the purposes of this paper, an uncontrolled or abandoned hazardous waste site is defined as having one or more of the following characteristics: (1) is no longer used or is inactive and is no longer maintained; (2) is a location of unpermitted or improper waste disposal; (3) has no known owner; and (4) containment and monitoring techniques are inadequate.

Quince, J.R., "Monitoring, Recovery and Treatment of Contaminated Ground Water", Proceedings of the Second National Symposium on Aquifer Restoration and Ground Water Monitoring, 1982, National Water Well Association, Worthington, Ohio, pp. 58-68.

With ground water monitoring being implemented, it is becoming increasingly apparent that there exist many areas of ground water contamination. The degree of contamination varies from site to site, usually dependent on the character of the chemicals involved and the time elapsed since contaminant occurrence. In many cases, the contaminant plume has not migrated far from the source and remedial measures are possible. Contaminated ground water can be removed using a variety of techniques ranging from simple French drain systems to more complex well field configurations. Recovered ground water is treated on-site with current wastewater treatment technologies applied in numerous configurations. Treatment system effluent is commonly used for aquifer recharge creating a closed system of injection and recovery. The area of influence is isolated from the aquifer system using hydraulic control. Monitoring the physical and chemical changes in the ground water before, during and after implementation, is required to determine the system efficiency. Aquifer rehabilitation technology is evolving through direct application of current concepts.

Quince, J.R., "Subsurface Hydrocarbon Spill Recovery", Proceedings of the Third National Symposium on Aquifer Restoration and Ground Water Monitoring, 1983, National Water Well Association, Worthington, Ohio, pp. 47-50.

Hydrocarbon spills may well be the greatest threat to ground water resources. Hydrocarbons cover a wide range of commonly used oils (typically fuel oils and gasolines) and chemicals (such as benzene and toluene). These substances are used by almost everyone in all parts of the nation. Spills of hydrocarbons primarily occur in response to transportation accidents and storage system failures. In particular, the storage of hydrocarbons in subsurface tanks at both public and private facilities create a great potential for environmental contamination. This paper presents information regarding methods for monitoring underground storage systems, investigation of hydrocarbon spills affecting soil and ground water and remedial alternatives. A number of case histories are reviewed to outline the various elements to be considered during site investigations and to illustrate some options for cleanup.

Quince, J.R. and Gardner, G.L., "Recovery and Treatment of Contaminated Ground Water", Proceedings of the Second National Symposium on Aquifer Restoration and Ground Water Monitoring, 1982, National Water Well Association, Worthington, OHio, pp. 58-68.

This paper presents information regarding underground recovery and treatment systems that have been applied to reclaim aquifers contaminated from a variety of sources. Aquifer rehabilitation is currently being considered, as an option for remedial action, at many locations across the United States. Published literature on this subject is limited, especially with regard to site-specific restorations. These systems have, however, been used in numerous cases for recovery and treatment of contaminated ground water following accidental spills of hazardous materials and contamination resulting from poor operational practice at various industrial facilities. Concepts for recovery and treatment of contaminated ground water are well established. It is the application of specialized techniques and equipment to real situations that has been limited. Recovery is accomplished using a variety of techniques, either singly or in combination, depending on site characteristics and contaminant(s) associated with the site.

Effluent from the treatment process can be effectively used for recharge to the aquifer actively flushing contaminants to the recovery system. This method creates a closed loop of recovery, treatment and injection that can continually treat the ground water until removal of contaminants has been accomplished. Ground water and system monitoring is required to follow the progress of the project. Four case histories are discussed briefly regarding recovery system, treatment methods used, and system efficiency at selected monitoring points.

Raymond, R.L., "Reclamation of Hydrocarbon Contaminated Ground Waters", undated, U.S. Patent Office 3, 846, 290, Washington, D.C.

This process involves elimination of ground water contamination by providing nutrients and oxygen for natural in-situ microorganisms. Further, removing water from the contaminated area is carried out until hydrocarbons are reduced to an acceptable level. Near a contaminated well a second well is drilled for use as an injector well. The injection well is equipped with a nutrient mixing tank, an injection tube, an air pump and a sparger. The contaminated well is pumped to cause water flow from the injection site to the contaminated sige. The injection well must be outside the perimeter of the contamination. Nutrients provided include nitrogen, phosphorus, and other inorganic salts. Liquid fertilizers are suggested in the 12-6-6 or 8-8-8 range. A concentration of 0.005-0.02 percent by weight of the formation water is suggested. The pH of the nutrient solution must be 6.5-7.5. To remove 1.25 tons of hydrocarbons per day 5 tons of air per day is required. If the above conditions are attained, and a growth rate of 0.02 grams per liter per day is attained, 90% of the hydrocarbons should degrade in six months. After the degradation is achieved the nutrient flow is stopped. This system is effective only in sites where the gasoline concentration is $\leq$ 40 ppm.

Rex Chainbelt, Inc., "Treatment of Acid Mine Drainage by Reverse Osmosis", Mar. 1970, Milwaukee, Wisconsin.

The report documents a study on the treatment of acid mine drainage by reverse osmosis. The objective of the study was to determine the feasibility of utilizing reverse osmosis to abate pollution due to acid mine drainage, and produce a water which could be used by industry or as a municipal water supply. A test site in Shickshinny, Pennsylvania was selected as a source of acid mine water for the study. A sample of this water was tested in a laboratory reverse osmosis unit to determine the design parameters for a 10,000 gallon per day demonstration unit. The results obtained during the demonstration period indicated that the reverse osmosis process has potential application in acid mine drainage treatment. A high quality water was produced which was suitable for use by industries or municipalities with a minimum of additional treatment. There are, however, operational problems which must be solved prior to utilizing reverse osmosis on a large scale. These include maintenance of high permeation rates through the membrane by reducing membrane fouling and determination of the optimum flow sheet for an acid mine treatment system utilizing reverse osmosis.

Rex Chainbelt, Inc., "Reverse Osmosis Demineralization of Acid Mine Drainage", Mar. 1972, Milwaukee, Wisconsin.

A two-phase study, involving both laboratory and field investigations, has demonstrated the feasibility of using reverse osmosis to provide potable water from acid mine drainage. The laboratory investigations involved the determination of methods for controlling iron fouling and the selection of a process flow sheet. During the field test, the process developed in Phase I was used to treat acid mine drainage from an underground aandoned anthracite coal mine. Treatment prior to reverse osmosis consisted of filtration (10 microns) followed by ultraviolet light disinfection. Brine from the RO unit was treated by neutralization, oxidation, and settling. Results obtained indicated that membrane fouling due to iron was satisfactorily controlled, but calcium sulfate fouling limited the recovery of product water to about 75%. Product water was of potable quality in all respects except for iron, manganese, and pH. Calcium sulfate precipitate on the RO membrane was successfully removed using a solution of ammoniated citric acid at pH 8.

Rich, C.A., "The Necessary Involvement and Responsibility of Separate Entities in Planning and Performance of Aquifer Restoration", Proceedings of the Third National Symposium on Aquifer Restoration and Ground Water Monitoring, 1983, National Water Well Association, Worthington, OHio, pp. 3-9.

A practical problem that may misdirect or inhibit appropriate abatement of ground water contamination is the potential misunderstanding or lack of communication that can develop between various parties involved in segments of applied remediation. Advance decision making is oftentimes controlled by the problem forum, preconceived objectives, the need to posture, experience gained elsewhere, institutional guidelines and one's personal perception of the problem. As a result, those charged with a responsibility to coordinate, investigate, design and operate or litigate contamination/cleanup are confronted with interpreting technical information that may or may not be complete or properly understood. Parties involved in effecting remediation are likely to demonstrate varying levels of participation, responsibility, influence and interest toward in situ ground water conditions, off-site impacts, actual vs. projected costs and solution attainability in the real world. Certain parties will be allowed greater or lesser flexibility at different stages in the program. Others, possibly central to key concerns, may only be introduced in a peripheral capacity. For example, the hydrogeologist, usually relied upon to define the "nature and extent" of a problem, provides critically important interpretation that dictates technical approach, degree of expenditure and relative significance of future decisions by others. Because it is his duty, with the support of associated disciplines, to provide hard facts on local ground water conditions, his interpretation becomes seriously consequential in modifying determinations on the applicability, feasibility and site suitability of categorical remedial alternatives. In overview, early recognition that remedial action's success or degree of success is contingent upon the quality, experience and communicative skills of its participants and their ability to objectively receive and evaluate field conditions in a cooperative atmosphere is paramount to securing an effective program. Experiences with remedial action development at an abandoned site, in the backyards of manufacturing plants and during the course of emergency spill response are used as illustrative examples.

Rishel, H.L., Boston, T.M. and Schmidt, C.J., Costs of Remedial Response Actions at Uncontrolled Hazardous Waste Sites, First Edition, 1984, Noyes Data Publications, Inc., Park Ridge, New Jersey.

This book presents conceptual design cost estimates for remedial response actions at uncontrolled hazardous waste sites. Thirty-five unit operations, covering uncontrolled landfill or surface impoundment disposal sites, were costed in mid-1980 dollars for the Newark, New Jersey area; and upper and lower cost averages for the contiguous 48 states were also prepared. The data in the book are based on a review of pertinent literature with subsequent conversion to a consistent computational framework such that costs of remedial response options can be readily compared. Capital costs for each unit operation were totaled. Overhead and contingency allowances were then applied. Total capital costs were not amortized, but rather assumed to be fully incurred in the first year. Operating cost components were also identified over a period extending 10 years from the time of initial application. Inflation was included in future operating costs. These were then discounted back to the first year, and added to capital costs to yield total life cycle costs in present value dollars. The result of this costing exercise is a set of unit costs for each remedial action unit operation. These costs are in terms of the unit of application for the remedial action itself (e.g., square meters of wall face for slurry cut-offs). It should be noted that resultant costs are "base construction costs", and costs attributable to the safety and health of on-site workers and off-site receptors must be added to these.

Rishel, H.L., et al., "Costs of Remedial Actions at Uncontrolled Sites", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1981, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 248-254.

During 1980, the U.S. Congress enacted the Comprehensive Environmental Response Compensation and Liability Act (CERCLA, also known as Superfund, P.L. 96-510) which was proposed to provide funds for the U.S. Environmental Protection AGency (EPA) to assist in the mitigation of pollution problems at uncontrolled waste disposal sites through remedial actions. This study was conducted to provide technical information to support this process; it was done to review, compile, update and integrate existing data on the costs of such remedial actions, in terms of discrete unit operations which could the nbe combined to construct conceptual remedial action scenarios. This type of review-and-update approach was considered more appropriate than additional conceptual design efforts because much conceptual design work had already been done. The design work which exists, however, is scattered, incomplete and inconsistent in methodology; much of it is out of date and vague either about the methods used to arrive at a cost figure or about what components the cost figure included.

Through the review-and-update approach, a consistent methodology on the existing data in terms of scope, location, time frame and cost computations was imposed. In addition, the missing details were supplied and results presented in a uniform format, with a minimum of overlap between the individual unit operations. The resulting document presents these data in a framework of a broad and consistent methodology, with enhanced detail.

Rocky Mountain Arsenal Contamination Control Program Management Team, "Selection of a Contamination Control Strategy for Rocky Mountain Arsenal", DRXTH-SE-83206, July 1983, U.S. Army Toxic and Hazardous Materials Agency, Aberdeen Proving Ground, Maryland.

Rocky Mountain Arsenal (RMA) is an Army installation, 27 square miles in area, located northeast of the city of Denver, and adjacent to Stapleton Airport. It is surrounded by residential, business, and agricultural real estate. Since 1942, RMA has been used by both government and industry as a site for the manufacture, testing and packaging of various chemical agents and commercial chemicals. Several areas of the property have become contaminated with organic and inorganic chemical wastes as a result of these activities. In 1974, chemicals directly associated with RMA activities were found in ground water north of the Arsenal. The Army thereupon established the Contamination Control (CC) Program at RMA to identify and quantify the various types of contamination migrating across the boundaries, determine contamination sources, and develop and implement appropriate measures to assure compliance with Federal and State Environmental laws. This report documents the results of a two and one-half year study of potential contamination control strategies for RMA to ensure compliance with State and Federal statutes pertaining to the release of pollutants to the environment. The report deals with an extensive technical review and analysis of migratory pathways of hazardous contaminants and their sources, an assessment of applicable environmental laws, development of corrective strategies within available technology, screening and evaluation of alternative strategies and selection of a preferred strategy.

Ross, L.W., "Removal of Heavy Metals from Mine Drainage by Precipitation", Sept. 1973, Denver University, Denver, Colorado.

Heavy metals in mine drainage waters of the Rocky Mountains can be removed by a two-stage process consisting of (1) neutralization followed by (2) sulfide treatment. The first stage removes ferric and aluminum hydroxides, and the second (sulfide) stage precipitates the heavy metals that are most objectionable as pollutants, and that are of possible interest for economic recovery. The two-stage process has been demonstrated in the laboratory and in a field experiment.

Rott, U., "Protection and Improvement of Groundwater Quality by Oxidation Processes in the Aquifer", Studies in Environmental Science: Quality of Groundwater, Vol. 17, 1981, Elsevier Scientific Publishing Company, Amsterdam, The Netherlands, pp. 1073-1076.

Oxidation processes in an aquifer caused by injection of oxygen containing water can improve the ground water quality and protect the ground water against pollution. The so-called subterranean ground water treatment has been applied in several European countries for some years. Stream and transport mechanisms and chemical and biological reactions as well are described. The recharge system in a most practical manner uses the pumping well for injection of oxygenated water into the soil.

Rulkens, W.H., Assink, J.W. and Van Gemert, W.J., "Development of an Installation for On-Site Treatment of Soil Contaminated with Organic Bromine Compounds", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1982, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 442-447.

Soil contamination is one of the most pressing of the environmental problems existing in the Netherlands. Over the last few years particularly, much attention has been given to this subject. At the present time, a large number of hazardous waste sites that need to be cleaned up have been discovered. Current methods for treating highly contaminated soil mainly involve excavation of the soil followed by thermal treatment elsewhere. This method is rather expensive and furthermore cannot be applied in all cases. Thus there is a need for less costly methods of cleaning up contaminated soil. A large number of process alternatives for cleaning up contaminated soils can be given. Some examples of these alternatives are extraction, chemical conversion and biological degradation of the contaminations in the soil. With the exception of thermal treatment, however, no other method of treatment has been developed for practical use so far. Much research and development work still have yet to be carried out with the attendant practical problem that each type of soil contamination is different. This also means that the method of treatment has to be adapted in each particular case. The investigation described in this paper deals with the development of an on-site treatment method for a soil strongly contaminated with organic bromine compounds. The contaminated site is located in the neighborhood of the Dutch municipality of Wierden. The main problem is the potential danger of the contamination of ground water used for the production of drinking water.

Ryan, C.R., "Slurry Cut-Off Walls, Methods and Applications", Mar. 1980, Geo'Con, Inc., Pittsburgh, Pennsylvania.

Slurry cut-off walls are non-structural walls constructed underground to act as barriers to the lateral flow of water and other fluids. Principal applications are site dewatering, pollution control, and seepage barriers in the foundations of water retaining structures. In this paper, the two basic types of trench -- soil bentonite (SB), and cement-bentonite (CB), and the principal kinds of slurry trenching equipment are discussed. There are examples of several recent projects with emphasis on the reasons behind the selection of the particular method. Slurry cut-off walls normally have a permeability in the range of 10^{-6} to 10^{-7} cm/sec. Recent advances in methods of analysis of slurry cut-off walls for the key factors of permeability and durability have provided much-needed assistance in the design process. The primary purposes of quality control are to check the continuity and depth of the wall, and to ensure a slurry and backfill which fall within workable limits while satisfying design criteria.

Sanning, D.E., "Surface Sealing to Minimize Leachate Generation at Uncontrolled Hazardous Waste Sites", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1981, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 201-205.

Many existing technologies, such as those currently being used for construction, hydrologic investigation, waste-water treatment, spill cleanup and chemical sampling and analysis, can be applied to uncontrolled hazardous waste sites. The minimization of surface infiltration will, in almost all cases, be an integral part of the remedial steps at those sites where the waste has been buried and the cost of removal is prohibitive. Minimizing surface infiltration typically consists of regrading, diverting surface water runoff and preventing or eliminating infiltration. The effectiveness of surface sealing depends upon the contribution of surface infiltration to the total problem at the site. From a cost effectiveness standpoint and ease of applicability, minimizing surface infiltration poses marked advantages over other types of remedial action unit operations. The Solid and Hazardous Waste Research Division of EPA has been involved eitehr directly, through actual EPA funding or indirectly through technically supported efforts at several sites where minimizing surface infiltration has been implemented. Two of those sites are discussed in this paper.

Schmidt, K.D., "Limitations in Implementing Aquifer Reclamation Schemes", Proceedings of the Third National Symposium on Aquifer Restoration and Ground Water Monitoring, 1983, National Water Well Association, Worthington, Ohio, pp. 105-109.

Often one of the first reactions to the discovery of polluted ground water is the urge to remove it by pumping. In the Southwest, there are a number of problems that may be encountered when attempting to pump polluted water. These include land ownership, water rights issues, adverse impacts due to pumping and disposal of treated water. In some cases, the land overlying a considerable part of the plume and downgradient area is under separate ownership from land where the pollution originated. Adjacent land owners may not even allow access for monitoring purposes, let alone for the drilling of new wells to pump polluted ground water. Thus it may not be possible to site recovery wells in the hydrogeologically preferred locations, which greatly limits the effectiveness of the reclamation program. In several states, polluted ground water cannot be pumped without first obtaining a special permit. In addition, in at least one case, the pumping of polluted water and subsequent disposal to an evaporation pond was ruled to be a waste of water, and hence this option was not possible.

Pumpage of polluted ground water from highly productive anisotropic alluvial aquifers is inherently inefficient. That is, the pumped water is generally a mixture of polluted and unpolluted water. This is especially true at sites where the vertical and horizontal extent of the plume have not been precisely determined, prior to installation recovery wells. At some operating reclamation projects, less than 20 percent of water pumped from recovery wells is polluted water. There can be large water-level declines in nearby wells, and in some cases pumps and wells have gone dry. Due to changes in the direction of ground water flow induced by pumping, substantial changes in ground water quality can result that were unforeseen prior to their occurrence. Disposal of the pumped water can be a major problem in some cases. Many plumes in the Southwest comprise tens or hundreds of thousands of acre-feet of polluted water. If it is not possible to treat and immediately use the pumped water, then there may be a substantial disposal problem. Recharge of treated water is difficult in some situations due to unfavorable soils and geologic conditions. Often, there are a substantial number of potential pollutants in the pumped water. If attention is focused on only one or several of these pollutants and comprehensive chemical analyses are not performed, then disposal of the water by land treatment can create additional ground water pollution. An example would be land spraying of a pumped polluted water in order to volatilize a specific organic constituent. Although the levels of the organic constituents in percolating water may be adequately reduced by this process, ammonia and organic nitrogen in the pumped water could be oxidized to nitrate. This could pollute ground water beneath the land disposal site.

Another problem in some aquifer reclamation schemes in the Southwest is that substantial amounts of pollutants are present in the vadose zone. Even after polluted water is removed from the aquifer, substantial pollution may occur due to slow drainage of polluted water from the vadose zone over many years and decades. In addition, specific pollutants may be adsorbed on solid materials in the aquifer. Later, some of these could be desorbed, and pollute relatively unpolluted water then present in the former plume. The majority of the problems in implementing aquifer reclamation projects in the Southwest have been due to one or more of the following factors: (1) the hydrogeologic system was not adequately understood prior to implementing the reclamation project; (2) the extent of the plume had not been determined; and (3) all potential pollutants in the plume had not been identified. In turn, these factors often appear to be related to two other phenomena. First is the lack of ground water hydrologists at the forefront of many reclamation projects. Second are the unreasonable time constraints imposed by some regulatory agencies, often because of intense public pressure.

Schuller, R.M., Beck, W.W., Jr. and Price, D.R., "Case Study of Contaminant Reversal and Groundwater Restoration in a Fractured Bedrock", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1982, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 94-96.

Ground water contaminated with trichloroethylene (TCE) was discovered in the vicinity of a manufacturing plant in southeastern Pennsylvania where contamination had resulted from a series of spills. Subsequent to this discovery, the plant contracted with SMC Martin to study the extent and magnitude of the TCE contamination in the vicinity of the plant and to develop an appropriate method for cleanup. A rapid response to cleanup of the ground water was desirable due to the potential for contamination of residential wells in the vicinity of the plant. However, the study was constrained by the availability of locations for well placement and limited client resources. As is typical of most industrial projects, the client and the regulatory agency were interested in a cost effective and efficient solution to the problem, which is rarely possible in the complex hydrogeologic conditions of southeastern Pennsylvania. However, the uniquely simplistic fracture system controlling ground water flow in the area resulted in a well-defined contaminant migration path which permitted a direct approach to contaminant reversal and ground water restoration.

Schuurmans, R.A., Steinmetz, J.J. and van den Akker, C., "Multi-Purpose Solution for the Protection Against Pollution of a Groundwater-abstraction for Watersupply", Studies in Environmental Science: Quality of Groundwater, Vol. 17, 1981, Elsevier Scientific Publishing Company, Amsterdam, The Netherlands, pp. 1083-1088.

The Municipal Waterworks of Amsterdam (G.W.) founded a ground water pumping station in the year 1888 north of the town of Hilversum, 25 km south-east of Amsterdam. In 1901 another water supply company, the "Midden Nederland" Water Works (W.M.N.), started in the same area. Already in 1875 the municipality of Hilversum made infiltration works for sewage water east of town, in an area with small lakes with a distance of about 1500 m south-east of the pumping stations. Together with the natural flow to the north-west, the recharged sewage water flows to the pumping stations and can cause trouble. During the last century new residential and industrial areas were built to the north of the old town of Hilversum. Today the border of the town is close to the pumping stations. The ground water below the town is polluted by sewage water from the leaky sewerage and probably by direct infiltration of sewage. The water level in the sandy subsoil is about 5 to 10 m below the land surface. From 1934 investigations were made to find a solution for the problem of pollution. In 1977 in the attracted ground water of G.W. a little amount of Trichloroethene (TCE) was discovered. This gave a start to a new approach to the problem.

Scott, R.E., Hill, R.B. and Wilmoth, R.C., "Cost of Reclamation and Mine Drainage Abatement: Elkins Demonstration Project", 1970, Robert A. Taft Research Center, Cincinnati, Ohio.

Acid mine drainage, discharging from coal beds, pollutes streams and rivers. An acid mine drainage reclamation project was established in the Roaring Creek-Grassy Run watershed near Elkins, West Virginia. The control costs established from the project are presented. The costs include those for clearing, grubbing, reclamation, and revegetation.

Sheahan, N.T., "Injection/Extraction Well System - A Unique Seawater Intrusion Barrier", Ground Water, Vol. 15, No. 1, Jan.-Feb. 1977, pp. 32-49.

A multiple-aquifer system in the bayfront area of Palo Alto, California, is being intruded with seawater from San Francisco Bay. In order to combat this potential degradation of the ground water supplies in the area, a sea water intrusion barrier is being constructed consisting of a series of injection wells used to inject 2.0 million gallons per day (7.6×10^6 l/d) of reclaimed wastewater into a shallow aquifer. The injected water is subsequently removed by a similar system of extraction wells to avoid any possible degradation of the water-supply aquifers from this source, and to allow reuse of the reclaimed wastewater. The investigation phase included test drilling, aquifer testing and injection testing to determine the feasibility of the injection/extraction concept. The number, spacing and location of I/E doublets were optimized using a digital computer model. The double-cased, double screened wells were constructed using corrision-resistant materials, and were designed for ease of routine maintenance. In operation, injection and extraction will be computer controlled by sensing piezometric levels in a series of monitor wells. Water pumped from extraction wells will be sold for industrial and agricultural purposes.

Shepherd, W.B., "Practical Geohydrological Aspects of Ground-Water Contamination", Proceedings of the Third National Symposium on Aquifer Restoration and Ground Water Monitoring, 1983, National Water Well Association, Worthington, Ohio, pp. 365-372.

An understanding of some basic aquifer properties and fluid distribution principles is necessary in order to assess and resolve underground contamination problems. The varied effects of petroleum product and chemical spills on land are discussed, including the physical and chemical properties of both the spilled product and the soil. The effect of capillarity in the funicular or transition zone during percolation, and lateral movement of mobile product is discussed. Particular emphasis is placed on determination of the volumetrics of recoverable hydrocarbons as analyzed from monitoring well data and aquifer soil properties. The technical aspects of hydrologic determination of the lateral extent of underground contamination are discussed. Also considered is the endurance of taste and odor from contaminated ground water after years of percolating rainwater representing many pore volumes of displaced fluid. Aspects of contaminant flow are emphasized, including contaminant plume velocity versus ground water flow. Spill mitigative measures for phase-separated product plumes are discussed, with the emphasis on practical aspects and field determinations. In addition, some aspects of hydrologic containment of contaminants are compared to physical barrier emplacement.

Shipps, M.H., "A Cost Effective Approach to the Clean-Up of Groundwater Spills", Proceedings of the Conference on Oil and Hazardous Material Spills: Prevention, Control, Cleanup, Recovery, Disposal, 1978, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 160-163.

New developments related to ground water spill clean-up are providing a more cost-effective approach to clean-up. Currently, difficulties are being encountered with the use of costly excavation techniques and inefficient recovery devices without the capabilities of hydrocarbon/water separation. Recent improvements in recovery well installation and in the development of in-ground hydrocarbon separations, coupled with an increased awareness of hydrogeological principles have significantly improved the state of the art. This new technique results in pure product recovery and provides an efficient and cost effective clean-up of the ground water.

Shuckrow, A.J., et al., "Bench Scale Assessment of Technologies for Contaminated Ground Water Treatment", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1980, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 184-191.

Contamination from unsecured industrial waste storage and disposal sites is a widespread problem. Often, this contamination manifests itself in the form of hazardous leachates and contaminated ground and surface waters. These contaminant streams are diverse in terms of composition and concentration -- varying from site to site, from location to location within a site and often over time at any given location. Some contaminant streams contain a broad spectrum of organic and inorganic constituents, while others have only a few compounds of concern. Regardless of whether contaminant streams are associated with active or abandoned sites, the need to detoxify/decontaminate these hazardous aqueous wastes sometimes arises. However, hazardous aqueous waste treatment for this application is not a routine operation. Little information on and/or experience with treatment technology applied to hazardous leachate or contaminated ground water exists.

In order to lessen this information gap, a project sponsored by the U.S. Environmental Protection Agency was undertaken to evaluate and verify selected concentration techniques for hazardous constituents of aqueous waste streams. This project entails literature search/data acquisition, desktop technology evaluations and experimental investigations to evaluate and adapt appropriate technologies for the applications of interest. The background of the study, and earlier efforts to compile data on hazardous waste problem sites and to screen pertinent treatment technologies have been reported elsewhere. Thus, the focus of this paper is upon the results of the desktop technology evaluations and upon ongoing experimental treatability studies. These treatability studies are being conducted at the Ott/Story site in Muskegon, Michigan.

Shukle, R., "Rocky Mountain Arsenal Ground Water Reclamation Program", Proceedings of the Second National Symposium on Aquifer Restoration and Ground Water Monitoring, 1982, National Water Well Association, Worthington, Ohio, pp. 366-368.

The most sizeable ground water contamination problem encountered in Colorado is the Rocky Mountain Arsenal. The Arsenal is a federal facility which has both manufactured and demilitarized chemicals and chemical-filled munitions plus leased facilities for pesticide manufacture. Generated wastes in the 1940s and 1950s were disposed of in several unlined lagoons. In 1975, the Department of Health issued orders to the Army and Shell Chemical Co. to respond to observed ground water contamination. Subsequent monitoring has identified unique organic contamination for more than 30 square miles. To date, the Army and Shell have been involved in monitoring, identifying contaminants, evaluating treatment alternatives, identifying hydrogeologic conditions, testing pilot systems and designing and constructing full-scale treatment facilities. The extended north boundary treatment system is 6,700 feet long, averages 25 feet deep, contains both dewatering and rejection wells, functions with a bentonite barrier and handles about 400 gpm of water. The northwest boundary system is 1,700 feet long, wells range from 65 to 85 feet deep, initial flows were 1,600 gpm with projected flows at 700 gpm and functions with a hydrologic barrier, as opposed to a bentonite barrier. Both systems include activated carbon treatment for removal of organics.

Shultz, D.W. and Miklas, M.P., "Assessment of Liner Installation Processes", Proceedings of the Sixth Annual Research Symposium on Disposal of Hazardous Waste, 1980, U.S. Environmental Protection Agency, Cincinnati, Ohio, pp. 135-159.

Southwest Research Institute is conducting a study to identify current methods and equipment used to (1) prepare supporting subgrade and (2) place liners at various impoundments in the United States. Subgrade preparation and liner placement activities have been observed at fifteen sites to date. The sites selected have included landfills, wastewater impoundments, and potable water reservoirs. Information obtained during each site visit included: (1) methods and equipment used to prepare the subgrade upon which the liner is to be placed; (2) methods and equipment used to place the liner material; (3) special problems encountered and their solutions; and (4) important characteristics which must be considered during design and construction of an impoundment facility. Various aspects of subgrade preparation and liner placement are discussed herein. Photographs depicting construction and placement activities are also presented.

Shultz, D.W. and Miklas, M.P., "Procedures for Installing Liner Systems", Land Disposal of Hazardous Waste: Proceedings of the Eighth Annual Research Symposium, 1982, U.S. Environmental Protection Agency, Cincinnati, Ohio, pp. 224-238.

The field placement procedures used to construct a variety of generic types of liner systems for landfills and surface fluid impoundments are discussed. These include procedures to install flexible polymeric membranes, sprayed-on membranes, native materials, soil sealants and admixes. In addition to placement procedures, methods and equipment used to prepare and subgrades are discussed. Placement procedures used to install polymeric liner systems have certain commonalities, such as anchoring methods and approaches to material positioning. There are differences, however, with respect to seaming technology. For example, solvents and heat are two methods used to field seam the same material. Liner material placement procedures and subgrade conditions as recommended by manufacturers and installers are compared to field observations. Generally, field practice appears to follow these recommendations. The critical aspects of subgrade preparation and liner placement generally accepted by the industry as important to a good job include proper subgrade compaction, installation by knowledgeable, experienced crews familiar with the liner material, and a strong quality assurance program during installation.

Silka, L.R. and Mercer, J.W., "Evaluation of Remedial Actions for Groundwater Contamination at Love Canal, New York", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1982, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 159-164.

During the coming years, considerable effort and resources will be committed to the investigation and clean up of ground water contamination caused by hazardous waste disposal, spills and other activities. To optimize the limited resources available for the solution of these problems, and maximize the protection of public health and the environment, remedial actions must be adequately selected, designed and monitored. Ground water modeling is an excellent planning tool that can assist in the evaluation and selection of remedial actions. Modeling provides quantitative analyses of site hydrology and allows prediction of the effects of proposed remedial actions on the fate of subsurface contaminants. Simulation of remedial actions during the planning stages can provide decision makers with considerable insight for making decisions on appropriate actions to be taken at a site. Such a tool, applied from the outset of a remedial action, can reduce trial and error, costs, and time on a project. Modeling, in addition, provides the means to predict future consequences of planned actions.

Sills, M.A., Struzziery, J.J. and Silbermann, P.T., "Evaluation of Remedial Treatment, Detoxification and Stabilization Alternatives", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1980, Hazardous Materials Control Research Institute, Silver Sprin, Maryland, pp. 192-201.

Uncontrolled hazardous waste sites, such as Love Canal, New York, Woburn, Massachusetts and the Valley of the Drums, Kentucky, are symbolic of both a national problem and a national commitment. The environmental and public health hazards associated with these sites have emphasized the need to escalate regulatory control efforts, technical evaluations and the financial investments required for the identification, cleanup and remedial management of all existing uncontrolled hazardous waste sites. For those cases where excavation, removal and off-site disposal of hazardous materials from an uncontrolled site are employed, the technical, economic and environmental evaluations are normally straightforward and limited to the actual excavation, hauling and final disposal activity. In these cases, the private contractor with the lowest bid is usually the most cost-effective alternative. A more typical and difficult problem, however, is the case of in situ or in-place contamination of the subsurface soil matrix or ground water under an uncontrolled site, due to the leaching of hazardous substances. Subsequent contamination of adjacent surface water bodies by direct runoff of hazardous substances or recharge by contaminated ground water is an equally serious companion consideration. The evaluation of a wide range of remedial treatment, detoxification and stabilization alternatives for these situations require a systematic method of analysis in order to accurately compare the technical, economic and environmental impact aspects of each remedial management option under consideration. This paper describes the basic on-site treatment, detoxification and stabilization alternatives available for the remedial management of uncontrolled hazardous waste sites and outlines a systematic evaluation procedure that can be used to identify the most cost-effective, environmentally sound alternative for a given site. This procedure was initially developed for the evaluation of existing hazardous waste sites in New England.

Sims, R.C. and Wagner, K., "In Situ Treatment Techniques Applicable to Large Quantities of Hazardous Waste Contaminated Soils", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1983, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 226-230.

> Uncontrolled disposal of hazardous wastes frequently results in the production of large quantities of contaminated soils. It is often cost prohibitive or impractical to excavate, haul and dispose of these soils in an approved landfill. In situ treatment of these soils was investigated in this project as an alternative. The approach to treating soils is based on: (1) fundamental soil chemical, physical and biological processes, (2) methods developed for land treatment of industrial wastes and (3) hazardous waste land treatment (HWLT) regulations recently promulgated in 40CFR, part 264, 1983. The goals of in situ management include treating contaminated soils until an acceptable level is achieved and protecting ground water and surface water resources without physically removing or isolating the contaminated soil from the contiguous environment.

Spencer, R.W., Reifsnyder, R.H. and Falcone, J.C., Jr., "Applications of Soluble Silicates and Derivative Materials in the Management of Hazardous Wastes", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1982, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 237-243.

> Soluble silicates are currently being used in chemical based methods of waste disposal, but the authors feel they could be utilized much more. This report is a review by the authors of the literature pertaining to waste treatment for disposal, with emphasis on solidification of liquids and sludges. The chemical methods currently used, using both silicate-based, and those that use silicates indirectly, are described. Some theoretical papers with implications for this use are reviewed, and possible new ways of using silicates are described; solidifying solvents for transportation; grouting landfills to reduce permeability and divert or block subsurface flows; and modifications of other processes to improve leaching and physical properties.

Spooner, P.A., Wetzel, R.S. and Grube, W.E., Jr., "Pollution Migration Cut-Off Using Slurry Trench Construction", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1982, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 191-197.

> Over the last two decades, cut-off walls emplaced by slurry trenching have been installed at many solid and hazardous waste facilities. This paper presents the interim results of a project

for USEPA's Office of Research and Development to develop a technical handbook on the use of slurry trenching techniques to control pollution migration. Slurry trenching is a method by which a continuous trench is excavated (by backhoe or clam-shell grab) under a slurry of bentonite and water. This slurry, or more correctly, colloidal suspension, supports the trench walls and allows excavation to greater depths with no other means of support. Once a trench has been excavated under slurry to the required depth and length, it is backfilled to form a continuous, nearly impermeable barrier, or cut-off wall, to ground water flow. In some cases, the slurry is a mixture of water, cement, and bentonite which hardens in place to form the final barrier. In other instances, this trenching technique is used to place soil-bentonite cut-off walls, where the backfill is composed of the excavated soil with small amounts (1 to 4%) of bentonite added. In some instances, borrowed soil materials, such as additional fines, or gravel may have to be added to meet the requirements of lower permeability or higher strength. Another variation of this technique, seldom used for pollution migration control, is the use of pre-cast or cast-in-place concrete diaphragm walls, which are installed when both pollution migration cut-off and structural support are required.

Spooner, P.A., et al., "Compatibility of Grouts with Hazardous Wastes", EPA-600/52-84-015, Mar. 1984, U.S. Environmental Protection Agency, Cincinnati, Ohio.

A study was conducted to determine existing information on the compatibility of grouts with different classes of chemicals. The data gathered can be used as a guide for testing and selecting grouts to be used at specific waste disposal sites with various leachates.

The 12 types of grouts used in this study were chosen because of their availability and use in waterproofing and soil consolidation projects. These grouts are bitumen, Portland cement Type I, Portland cement Types II and V, clay, clay-cement, silicate, acrylamide, phenolic, urethane, urea-formaldehyde, epoxy, and polyester. Sixteen general classes of organic and inorganic compounds are also identified as being the types most likely to be found in leachate from a hazardous waste disposal site. The known effects of each chemical class on the setting time and durability of each grout are identified and presented in a matrix. These data were based on a review of the available literature and contact with knowledgeable persons in industries, universities, and government agencies. The physical and chemical properties, reaction theory, and known chemical compatibility of each grout type are discussed. Since compatibility data are not complete for each grout type, predictions are made where possible for the silicate and organic polymer grouts based on their reaction theory. These results are also presented in a matrix.

To establish the compatibility of chemicals with grouts, a series of laboratory tests should be performed. The two grout properties that must be addressed are permeability of the grouted soil and set time of the grout. No established testing procedures are identified in the literature for determining the effects of chemicals on these grout properties. Fixed-wall and triaxial permeameters, which are used for soil testing, can be used for measuring the effects of chemicals on permeability. No single procedure applies to all grout types for determining set time. Visual observation is the easiest method, though somewhat subjective. The selection of a grout for a specific waste site depends on its injectability, durability, and strength. These factors relate site hydrology, geochemistry, and geology to grout physical and chemical properties.

Srivastava, V.K. and Haji-Djafari, S., "In Situ Detoxification of Hazardous Waste", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1983, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 231-236.

Uncontrolled disposal of hazardous wastes usually results in contamination of soil and rock followed by ground water contamination. The removal of contaminated ground and emplaced waste is costly and often impractical. Open excavation requires careful transportation of contaminated mixtures and disposal in a safe landfill. An alternative to contaminated ground removal is in situ treatment or detoxification. Although many of the fundamental concepts of in situ detoxification are known, and others are being studied at several laboratories, the feasibility assessment has not been collectively considered for different applications, mainly because these technologies are either in the conceptual or early infancy stage. Recently, the USEPA began a research program at the Municipal Environmental Research Laboratory, Cincinnati, Ohio, to investigate in situ treatment of hazardous wastes. A literature search has been conducted to identify the technologies that either exist or have the potential for further investigation. The most common technologies considered for in situ treatment include: immobilization; biodegradation; neutralization; solvent mining; and oxidation-reduction.

One significant limitation of in situ treatment is that it is waste specific. Heavy metals, pesticides, residues, organic solvents, inorganic salts, explosives, etc., have their own chemical properties and require different treatment. Proper identification of wastes and their physical, chemical and toxicological properties is vitally important to determine the best strategy planning for in situ treatment to avoid undesirable reactions or production of additional unwanted toxic species. The applications of in situ detoxification technologies for organic and inorganic contaminants are identified and their applications are assessed with particular regard to their: availability -- commercially developed, pilot plant or laboratory scale; feasibility -- design, construct and operation feasibility; cost-effectiveness -- design, construction and operational cost; advantages and disadvantages -- unwanted chemical reactions or end products; environmental impact -- assess environmental hazards, spread of contamination; and safety method -- personnel safety.

St. Clair, A.E., McCloskey, M.H. and Sherman, J.S., "Development of a Framework for Evaluating Cost-Effectiveness of Remedial Actions at Uncontrolled Hazardous Waste Sites", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1982, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 372-376.

Many uncontrolled hazardous waste sites across the nation are currently being "cleaned up" or are slated for remedial action implementation in the near future. An initial step in any remedial action plan at hazardous waste sites is identification of potential remedial alternatives, followed by the selection of the most appropriate one. The formality required in this identification/selection phase may be dependent on the source of funding for the remedial action. For example, CERCLA requires that remedial action conducted using Superfund monies be demonstrated to be the cost-effective alternative that adequately protects human health and the environment. Whether state agencies or private contractors use a cost-effectiveness assessment per se, some procedure is necessary to select the most appropriate plan from a list of potential alternatives.

In the first part of this paper, the authors discuss the concepts related to cost-effectiveness and their applicability to assessment of remedial action alternatives. After reviewing these concepts, the development of a specific methodology for systematic, accurate assessments of potential remedial action plans it outlined. In developing a methodology for assessing cost-effectiveness, the objectives and criteria which must be met should be well defined. One major purpose of the cost-effectiveness framework is to promote consistency in decision-making while maintaining applicability to widely varying situations. The methodology must be simple to apply, requiring only minimal instructions on its use. In this regard, the analysis should be based on the smallest possible number of independent variables that address all relevant concerns. Because of the nature of the problem at uncontrolled hazardous waste sites, the methodology must not be dependent on large amounts of information, either on site conditions or on the remedial alternatives being considered.

However, the method must readily allow for consideration of newly obtained information if it becomes available. In addition, it should not be overly quantitative or impose a precision on the analysis that is inconsistent with the degree of knowledge about the problem or expected results. Finally, the methodology should incorporate a means for determining the sensitivity of the analysis to judgments made in applying it.

Stief, K., "Long Term Effectiveness of Remedial Measures", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1982, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 434-436.

The effectiveness of widespread remedial actions can only be proved in the field by a decrease in contamination, e.g., decreasing ground water pollution. The aim of assessment of long-term effectiveness is to find the point in time, at which a remedial action must be repeated. Constructional sealing measures can be expected to be effective for a maximum period of 50-100 years, which is accepted as a reasonable depreciation period in civil engineering. Whether particular chemical or microbiological strains at a contaminated site causes a shorter useful life time, must be checked by monitoring. If the contaminants, which contained by capping or barrier-system are not changed within this "calculated" lifetime, so that the hazardous contamination, present at the beginning of remedial action, has decreased to an acceptable threshold, a new remedial action scheme has to be designed. However, the degree of contamination present at this time may require less stringent remedial methods. The objective of monitoring these facilities is to check the accuracy of the assumption of long-term effectiveness, so that the remedial measures can be renewed before if needed at the appropriate time.

Stover, E.L., "Removal of Volatile Organics from Contaminated Ground Water", Proceedings of the Second National Symposium on Aquifer Restoration and Ground Water Monitoring, 1982, National Water Well Association, Worthington, Ohio, pp. 77-84.

Indiscriminate disposal of industrial wastes has become one of the most important environmental issues facing the United States today. A serious threat from these activities is contamination of drinking water supplies by a variety of organic compounds. Contamination of ground water supplies by organic compounds, including volatile organics commonly found in many industrial cleaning solvents, has recently received widespread media coverage. The feasibility of removing volatile organic compounds from contaminated ground water has evaluated in parallel activated carbon adsorption and air-stripping studies. The removal of 1,1,1-trichloroethane detected at levels of concern, as well as other volatile organics detected in lower concentrations, were investigated in pilot scale studies. The 1,1,1-trichloroethane could be effectively air-stripped to less than 10.0 ppb with other volatile organics stripped to less than 1.0 ppb.

Sudat, M.M., Mateo, M. and Farro, A., "Management Plan for Hazardous Waste Site Cleanups in New Jersey", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1983, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 413-419.

A Management Plan for hazardous waste site mitigation has been prepared by the Department of Environmental Protection (DEP), Division of Waste Management, of the State of New Jersey, for the period of 1983-1986. The purpose of the plan is to develop a systematic approach to remedial action at hazardous waste sites, to coordinate cleanup and enforcement actions and to identify future funding needs and sources. There are a total of 106 hazardous waste sites identified in the plan. These include: 65 sites on the National Priorities List (NPL) issued by the USEPA on Dec. 20, 1982 and eligible for Federal Superfund monies and 41 sites which were not included on the NPL. Thirty-four drum dump sites listed in the draft plan approved by USEPA on Apr. 11, 1983, were cleaned up in 1983. Those sites not on the NPL will be addressed through New Jersey's Spill Compensation Fund and Hazardous Discharge Fund as were the recently cleaned up sites. While cleanup projects are expected to be initiated within the period of the plan, completion of cleanups at all scheduled sites will be a seven- to eight-year effort with some sites requiring maintenance for many years beyond that time. The plan also lists the 68 hazardous waste sites with over 10,000 drums cleaned up by DEP since 1980 at a cost of approximately $3 million. Including the $26 million spent on cleanup of Chemical Control in Elizabeth and $6 million on Goose Farm in Plumsted Township, the state's cost for remedial work at these 70 hazardous waste sites is over $35 million to date.

Swinnerton, C.J., "Protection of Groundwater in Relation to Waste Disposal in Wessex Water Authority", Studies in Environmental Science: Quality of Groundwater, Vol. 17, 1981, Elsevier Scientific Publishing Company, Amsterdam, The Netherlands, pp. 1089-1095.

Wessex Water Authority as one of the ten water authorities in England and Wales has the responsibility of liaising the waste disposal authorities which are the County Coucils to ensure that both ground water and surface water resources are not polluted by waste disposal activities. All new waste disposal sites require both planning permission and a site license, and both these authorisations are referred to the water authority for comment. Conditions can be requested for inclusion on both so that adequate protection is afforded. Failure for agreement on conditions necessary can be referred to the Secretary of State for decision. Several water authorities have developed aquifer protection policies in which the aquifers are specified as either requiring various degrees of protection or in some cases as being of minimal resource value and therefore not justifying protection.

Within Wessex no aquifer protection policy as such has been developed although the general policy adopted in waste disposal liaison is to discourage waste disposal sites on aquifers. However, taking a realistic view and bearing in mind the need to balance the various interests involved, as required by Government, each site is looked at on its individual merits and disadvantages, and sites on aquifers are permitted, subject to adequate safeguards, if the need is sufficiently great. In addition, preference is given to the "contain and treat" approach rather than the "dilute and disperse" unless adequate evidence is available to support the latter.

Of the 9918 km^2 total Wessex area, 36% is outcrop of a wide range of aquifers found in Wessex, and these provide water for approximately half of the total public water supply demand which is around 900 megalitres per day at present. Clearly with ground water contributing such a high proportion of potable supplies it is essential that due regard is given to its protection in siting waste disposal sites. The practical approach of looking at sites individually and accepting sites on aquifers where sufficient reliable evidence is provided to show that no harmful effects to ground water will result has been well accepted by the counties, this being demonstrated by the fact that only one site has been referred to the Secretary of State for decision due to failure to agree between Wessex and a county.

Tewhey, J.D., Sevee, J.E. and Fortin, R.L., "Silresim: A Hazardous Waste Case Study", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1982, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 280-284.

The Silresim Chemical Corporation's chemical waste reclamation facility in Lowell, Massachusetts was abandoned in Jan. 1978; approximately one million gallons of hazardous material were left behind in drum and bulk storage. The five-acre reclamation facility, established in 1971, had been accepting approximately three million gallons of oil wastes, solvents, chemical process wastes, plating wastes, heavy metal containing sludges and other materials yearly. The facility was designed and licensed for the ultimate disposal or recycle of these chemical wastes. Site investigations conducted in 1977 revealed license violations; the license was revoked when Silresim declared bankruptcy later that year. The Commonwealth of Massachusetts, Department of

Environmental Quality Engineering (DEQE) initiated efforts to clean up the site and by Sept. 1981 all stored materials had been removed. In Oct. 1981, a two-part study was initiated to characterize the nature and extent of soils and ground water contamination caused by the hazardous materials and to recommend actions to remedy the contamination problem.

Texas Research Institute, Inc., "Final Report, Underground Movements of Gasoline on Groundwater and Enhanced Recovery by Surfactants", D743 (1-3) - F, Sept. 1979, American Petroleum Institute, Washington, D.C.

A combination of anionic and nonanionic surfactants (Richonate YLA [77030-90-1] and Hyonic PE 90 [65035-40-7]) was most effective in displacing gasoline from 1-dimensional sand-pack models of an aquifer. A 2-dimensional model simulating a soil section from a gasoline spill zone to a recovery well showed that the surfactants acted by 2 mechanisms: simple displacement of the gasoline and draining of the capillary zone which allowed immobile gasoline to drain to a narrower zone and flow to a recovery point.

Texas Research Institute, Inc., "Enhancing the Microbial Degradation of Underground Gasoline by Increasing Available Oxygen", 8081 (FR) WLM, Feb. 1982, American Petroleum Institute, Washington, D.C.

The objective of this work was to develop means of enhancing the microbial degradation of gasoline in the subsurface soil strata by increasing the available oxygen. The project consisted of two phases -- a literature survey, followed by the experimental work. Several papers were found concerning the biodegradation of gasoline in ground water, but none with regards to the subsurface soil strata. The first aim of the literature review was to develop a thorough characterization of the hydrocarbon oxidizers and, from this, propose "ideal" degradation conditions. Focus was then brought on methods, both physical and chemical, for oxygenating the biodegradation environment. Only two physical means were proposed. Roto-tilling was deemed feasible for aeration of shallow contaminated areas and soil venting with liquid oxygen or air was a possibility for deeper contamination. Chemical techniques cited included decomposition of peroxides and superoxides, as well as peroxyacids and salts. Considering all possibilities, three approaches were deemed feasible. These were the injection of liquid oxygen or air, the injection of oxygen releasing compounds along with nutrients, and simple venting, if the soil was porous. The chemical costs were listed with regards to the cost per pound of oxygen produced. Liquid oxygen, compressed oxygen, and 35% hydrogen peroxide were the three cheapest chemicals. All things considered, the injection of H_2O, along with the necessary nutrients was deemed the most beneficial method.

The experimental phase examined the toxicity of H_2O_2 to the hydrocarbon utilizers in a liquid medium under various H_2O_2 and microbial concentrations. It was found that H_2O_2 was toxic at concentrations of $\geq$ 100 ppm to new cultures ($>$ 2 days old) could withstand concentrations as high as 10^3 to 10^4 ppm. In fact, it was seen that bacterial growth, at times, exhibited an increase, probably due to H_2O_2 decomposition. As the concentration of microorganisms increased, a higher concentration of H_2O_2 was required to be toxic. The final phase of the experimental work was an attempt to look at the toxic effects under constant H_2O_2 concentrations in a sand packed column. Problems resulted when bubble formation in the column caused a blockage of the H_2O_2 flow, even at concentrations as low as 100 ppm.

Thompson, S.N., Burgess, A.S. and O'Dea, D., "Coal Tar Containment and Cleanup Plattsburgh, New York", *Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites*, 1983, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 331-337.

A gas generating plant was operated along the banks of the Saranac River in the City of Plattsburgh, New York, from 1896 to 1960. Coal tar, a by-product of the gasification process, was intermittently disposed of in unlined ponds adjacent to the river. Throughout the years, the coal tar has migrated through the substrata resulting in periodic coal tar release into the river. Acres American Incorporated (Acres), Buffalo, New York, was retained in 1979 to: identify the extent of coal tar contamination; define the physical and chemical properties of the contaminant; define the mode of contaminant transport; define and assess the corrective remedial alternatives; perform final design; and provide construction supervision and management. The work was undertaken in a multi-phase approach from 1979 to 1982. In this paper, the authors discuss the site investigation, remedial alternatives and final design and construction undertaken at the site.

Threlfall, D. and Powiak, M.J., "Remedial Options for Ground Water Protection at Abandoned Solid Waste Disposal FAcilities", *Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites*, 1980, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 131-134.

The selection of remedial options at abandoned solid waste disposal sites is a function of economic and technical feasibility. A site investigation to determine subsurface conditions and waste characteristics is necessary to choose the best option. Under certain circumstances, limited remedial measures may be sufficient. In others, though, extensive measures may be required despite higher costs. The case study presented herein demonstrates that a thorough understanding of subsurface conditions and the waste characteristics determined the selection of viable remedial options. The use of natural barriers, such as the local soil cover and underclay, to control leachate and ground water flow direction reduced engineering costs without neglecting environmental concerns. The case study also shows that further laboratory and field investigations may be required to determine what remedial options are feasible. In this case, tests of compacted cover material had to be performed to determine if required low permeability values could be attained. By utilizing the results of the detailed site investigation and conducting permeability studies, the most economical yet technically and environmentally effective remedial measures to protect ground water were selected.

Thurrott, J.C., et al., "Trihalomethane Removal by Coagulation Techniques in a Softening Process", EPA-600/52-83-003, Mar. 1983, U.S. Environmental Protection Agency, Cincinnati, Ohio.

This research program investigated various potable water treatment processes in combination with lime softening to effect maximum removal of trihalomethane precursor compounds. A study of the literature was used to guide the initial test work. Bench-scale jar tests investigated various combinations of coagulants that earlier studies indicated would be promising. The test work evaluated the relative effectiveness of lime softening, alum coagulation, ferric coagulation, and clay coagulation with respect to their ability to remove THM precursors by themselves and in various combinations with lime softening. The bench-scale test work was followed by a series of eight pilot-plant test runs using the U.S. Environmental Protection Agency's trailer-mounted pilot facility at the 45.4-MLD (12-MGD) Water Treatment Plant in Daytona Beach, Florida. The raw water studied is a moderately colored, high-hardness ground water emanating from the Floridan aquifer. Various treatment processes studied included single-stage coagulation/lime softening, two-stage coagulation/lime softening, lime softening/coagulation, bentonite clay with lime softening, and polymeric coagulant/clay coagulation/lime softening. Extensive analytical data were collected and summarized on raw water for test samples, pilot-plant process waters, treatment plant samples, and Daytona Beach distribution system samples. These data were used to evaluate the effectiveness of each process studied, as well as to compare pilot-plant performance with full-scale plant results.

Tolman, A.H., et al., "Guidance Manual for Minimizing Pollution from Waste Disposal Sites", EPA-600/2-78-142, Aug. 1978, U.S. Environmental Protection Agency, Cincinnati, Ohio.

The purpose of this manual is to provide guidance for municipal officials nd engineers in the selection of available engineering technology to reduce or eliminate leachate generation at existing dumps and landfills. The manual emphasizes remedial measures for use during or after closure of landfills and dumps which do not meet current environmental standards. All of these measures must be designed and engineered by competent professionals for each specific site. Some of these measures are passive, that is, they require little or no maintenance once emplaced. Others are active and require a continuing input of manpower or electricity. Since the emphasis of this manual is on techniques of reducing leachate generation or controlling its movement, leachate treatment processes per se are not detailed.

Most of the techniques discussed deal with the reduction or elimination of infiltration into landfills in one of five categories: surface water control, passive ground water management, active ground water or plume management, chemical immobilization of wastes, and excavation and reburial. The technology presented is widely used in construction but has not necessarily as yet been applied to landfill closure. Surface water control measures include contour grading, surface sealing, and revegetating the landfill. These methods reduce infiltration of precipitation through the landfill surface, involve standard engineering procedures, and provide means of finishing the site. Passive ground water control techniques are used to minimize infiltration of ground water into the fill. They involve more technically advanced engineering procedures designed to provide an underground barrier between the ground water and the landfill. They are generally more costly and are useful for isolating a landfill when applied in conjunction with surface sealing methods. Plume management procedures involve actively altering the course of leachate movement by either adding or removing water from around the landfill. These methods can effect greater changes in water table elevations than can passive barriers but require continued maintenance and energy supplies and are therefore more costly.

Truett, J.B., Holberger, R.L. and Sanning, D.E., "In Situ Treatment of Uncontrolled Hazardous Waste Sites", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1982, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 451-457.

Problems associated with contaminated lands -- lands used directly as waste disposal sites or contaminated as a result of industrial or other activities -- are common throughout the NATO alliance and many other industrial nations. These problems range from imminent health and environmental hazards posed by contaminants, to the increasing pressures to reclaim the land for safe, beneficial use.

The North Atlantic Treaty Organization's (NATO) Committee on the Challenges of Modern Society (CCMS) is studying in situ treatment of contaminated lands. Portions of the study are being conducted in several nations. The Netherlands are evaluating in situ treatment applications in gas works and other chemically contaminated sites. The United Kingdom has completed a grouting feasibility study and is evaluating an experimental study of shallow-depth grouting problems. The Federal Republic of Germany has treated arsenic-contaminated soils and ground water by injection of permanganate solution, and has investigated the effects in ground water of silicate-gel injections used to consolidate foundation soils. The United States has recently completed a study on in situ techniques of solidification/stabilization using one actual site as a scenario for evaluating the feasibility of such treatment. These studies represent a substantial effort in the evaluation and application of in situ treatment techniques. Certain of the in situ treatment techniques were not only to reduce the pollution impacts from contaminated soils, but also to improve the properties of the soils for certain end uses of the site. Selected grouts, for example, not only immobilize specific pollutants, but can increase the load-bearing properties of the soil in a contaminated area intended for eventual use as a building site.

Trussell, R.R., Trussell, A. and Kreft, P., "Selenium Removal from Ground Water Using Activated Alumina", EPA-600/2-80-153, Aug. 1980, U.S. Environmental Protection Agency, Cincinnati, Ohio.

Selenium is a contaminant found in trace quantities in some ground- and surface-waters in the United States. Two species of inorganic selenium, with valence states of +4 and +6, are typically found in selenium-contaminated waters. Se(IV) and Se(VI) act very different, chemically. Se(IV) occurs as $HSeO_3^-$ in the pH range of 2.7 to 8.5. Se(VI) occurs as $SeO_4^=$ above pH 1.7. The valence of either of these species is thought to be determined by the oxidation-reduction potential of a water at a certain pH. Knowing the oxidizing stte of a water, one can predict whether Se(IV) or Se(VI) should be present.

Initial batch studies indicated that Se(IV) was preferentially adsorbed over Se(VI) in side-by-side tests. The isotherm capacity of activated alumina for Se(IV) was roughly three times the capacity of Se(VI). Other studies indicated that while bicarbonate mildly interfered with Se(IV) removal, both bicarbonate and sulfate heavily interfered with Se(VI) adsorption. Initial column studies with a three-inch deep bed helped delimit the amounts of NaOH and H_2SO_4 to be used during regeneration of Se(IV)-saturated alumina. Other items addressed in the three-inch column studies included how varied concentrations of NaOH and H_2SO_4 affected regeneration capabilities and how the varied concentrations affected alumina degradation. Deeper (9-inch) column studies showed that capacities for Se(IV) decreased with increasing influent water pH. pH 5 showed the highest capacity for Se(IV) adsorption. The kinetics of regeneration were the most important factors in determining the capacity of activated alumina for Se(IV), with pore diffusion seeming to be the rate-limiting step. Slow 0.5% NaOH flow rates (0.5 gpm/ft^2 or less) are necessary to effectively recover a high percentage of Se(IV) removed during a previous treatment run.

Tsand, C.F., Mangold, D.G. and Doughty, C., "A Study of Contaminant Plume Control in Fractured Porous Media", Proceedings of the Third National Symposium on Aquifer Restoration and Ground Water Monitoring, 1983, National Water Well Association, Worthington, Ohio, pp. 446-452.

A generic study has been carried out in the control and manipulation of a contaminant plume in an aquifer by production and injection procedures. The calculation is based on a numerical simulator CPT developed at the Lawrence Berkely Laboratory. The simulator employs an integrated finite-difference (IFD) numerical scheme and calculates coupled thermohydrologic flows with simple chemical advective transport in porous media with discrete fractures. It is a three-dimensional code that includes the effects of density and viscosity variations of the fluid, gravitation or buoyancy effects, aquifer heterogeneity and complex boundary conditions. The current version is derived from an early code PT which calculates heat and mass flows and which has been widely applied and validated in geothermal and non-isothermal hydrological problems. The paper applies this simulator to the study of a contaminant plume in four different types of media: (1) homogeneous porous medium; (2) porous medium with two regions of different permeabilities; (3) porous medium with a major fracture (or fault); and (4) multiple-fractured medium where the fractures can be represented statistically. In this generic exploratory study, two production-injection schemes are calculated for each case to investigate the transport and shape change of the contaminant plume. General discussions on the effectiveness and limits of such cleanup schemes are also made.

Tyco Laboratories, "Electrochemical Treatment of Acid Mine Waters", Feb. 1972, Waltham, Massachusetts.

Synthetic acid mine drainage (AMD) water was prepared by draining tap water through waste coal, and the resulting AMD was treated on a laboratory scale by an electrolytic oxidation process. Tests of fluidized bed, packed-bed, and annular flow prototype reactors demonstrated the packed-bed reactor to be most efficient. Oxidation of Fe(2+) to Fe(3+) takes place on a carbon electrode at a mass transport limited rate, while hydrogen evolution occurs on a polished 316 stainless steel cathode, limited by a slower electrochemical kinetic step. Preliminary economic analyses, using a packed-bed reactor are given. The electrolytic process is free from both the safety hazards associated with radio isotope-induced oxidation and the temperature dependence of biological oxidation methods.

Underwood, E.R. and Thornton, J.C., "Contaminated Ground-Water Recovery System Analysis, Design and Construction at a Waste Management Facility Located in a Guld Coastal Plain", Proceedings of the Third National Symposium on Aquifer Restoration and Ground Water Monitoring, 1983, National Water Well Association, Worthington, Ohio, pp. 142-147.

A shallow, saline, nonpotable saturated zone consisting of silty sand was slightly contaminated under a waste management facility located in a coastal zone. A 29-well ground water recovery system, using submersible pumps, showed a somewhat limited success in recovery and in effecting a cone of depression to halt the forward progress of the plume of contamination since low yield capacity of the saturated zone was not sufficient to continuously supply pumps at their minimum pumping rates. A detailed technical study was conducted to develop a high-yield recovery system to form a significant cone of depression and effect complete recovery of contaminated water. Hydrological data was gathered at all wells on-site by physical measurements and bailing tests. Field data and data from previous reports and literature was entered into a finite-difference ground water model. Once calibrated, the model was used to evaluate various recovery systems including jet-eductor pump systems, a French drain at the base of the saturated zone, recharge pits ahead of the plume and combination systems. The most effective system found was a combination of a 520-foot-long French drain and jet-eductor pumps capable of pumping at low formation yield located strategically in the plume of contamination. A French drain and four jet-eductor pumps were designed and installed. Pumping rates indicate a potential yield greater than expected. Recent monitoring indicates a positive change in ground water contours and formation of a cone of depression although the system is not operating continuously due to water-handling limitations. A water treatment system is being developed to treat the estimated volume of water to be recovered on a continuous basis.

Uniroyal, Inc., "Use of Latex as a Soil Sealant to Control Acid Mine Drainage", June 1972, Wayne, New Jersey.

Acid formation in a mine cavity can be prevented by keeping water (one of the reactants) out of the mine. This might be accomplished by forming a waterproof seal over the mine cavity to prevent the seepage of surface water into the mine. In laboratory tests using reconstructed soil columns, rubber latex showed good sealing efficiency. The ideal situation in which latex would coagulate in a narrow zone two to three feet below the surface by reacting with acidic or metallic constituents of the soil was not attained. Rather, in field tests the latex was deposited progressively. Latex stability appears to be a more critical property than latex particle size in controlling penetration. Addition of excess anionic surfactants to latex improved its penetration into the soil. Costs are discussed.

Unterbery, W., Stone, W.L. and Tafuri, A.N., "Rationale for Determining Prioroties and Extent of Cleanup of Uncontrolled Hazardous Waste Sites", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1981, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 188-197.

The Comprehensive Environmental Response, Compensation and Liability Act of 1980, PL 96-510, requires revision of the National Contingency Plan with a section known as the National Hazardous Substance Response-Plan and requires that the plan establish procedures and standards for responding to releases of hazardous substances, pollutants, and contaminants. One aspect of this new plan is defined as: "105 (3) methods and criteria for determining the appropriate extent of removal, remedy, and other measures as required by this Act." In this paper the authors attempt to develop a rationale for determining "appropriate extent of removal" for uncontrolled hazardous waste sites. This involves three types of decisions: (1) determination of cleanup priorities -- to what area or areas to direct the cleanup effort when time or resources are limited and/or the affected area is too extensie to clean up the entire release; (2) evaluation of alternative cleanup methods and selection of optimum methods -- once the priority cleanup areas have been selected, (a) to evaluate cleanup alternatives considering availability and cost of manpower and equipment, effectiveness and speed of deployment, effect on the environment and other applicable parameters; and (b) to select the optimum method or combination of methods for the priority cleanup operations; and (3) determination of extent of cleanup (how clean is clean) -- once the optimum cleanup methods have been selected, how far and how long should cleanup proceed? The desirable "extent of removal" depends on (a) reaching acceptably low levels of residuals, (b) the (usually rising) cost of removal per unit mass of contaminant as lower and lower contamination levels are achieved, (c) environmental impact of cleaning methods themselves; and other suitable parameters. The authors deal, in order, with these three questions and provide decision-making methodologies in these areas to assist those charged with directing cleanup operations.

U.S. Environmental Protection Agency, "Surface Impoundments and Their Effects on Ground Water Quality in the United States - A Preliminary Survey", EPA 570/9-78-004, June 1978, Washington, D.C.

Sections VIII and IX of this report address ground water pollution prevention techniques and the associated costs, respectively. The techniques are grouped into direct and indirect methods. Direct methods include: (1) installation of impermeable membranes; (2) installation of layer of impermeable material; (3) collection of contaminated water seeping from impoundment (infiltration galleries, wellpoint systems, and wells); (4) return of collected water back to impoundment; (5) physiochemical immobilization of waste material; (6) ground water cutoff wall (slurry trench, and grout cutoff); (7) capping of impoundment surface; and (8) treatment of contaminated water (equalization, biological treatment, activated carbon adsorption, heavy metals removal, dissolved solids removal) and treated water discharge. Indirect methods include development of a new source of water supply, and treatment of contaminated ground water prior to use. Size-independent cost figures for each of the methods are presented. The figures are based on available data and needed assumptions. Some of the resulting costs are actual numbers while some are cost relationships depicted graphically.

Villaume, J.F., Lowe, P.C. and Unites, D.F., "Recovery of Coal Gasification Wastes: An Innovative Approach", Proceedings of the Third National Symposium on Aquifer Restoration and Ground Water Monitoring, 1983, National Water Well Association, Worthington, Ohio, pp. 434-445.

Abandoned city coal gasification plants, which operated from the mid-1800s until just before World War II, are increasingly being identified as potential environmental troublespots because of the poor waste management practices which were used at the time. By 1920 there were more than 900 of these plants in existence in the U.S. One such abandoned plant site, which was the first site in the nation to receive emergency Superfund money for containment action, is located in Stroudsburg, Pennsylvania, along what was at one time a world famous trout fishery. A 1981 investigation of the site identified an eight-acre area contaminated with up to 1.8 million gallons of coal tar wastes from the old plant. Low-temperature coal tar is a complex misture of microscopic free carbon particles and some 10,000 individual organic compounds, only about 600 of which have ever been identified. Some of these compounds, such as anthracene and benzo(a)pyrene, are known or suspected human carcinogens. A large accumulation of stratigraphically trapped coal tar is currently being recovered by the present property owner through an in-ground pumping operation which relies on the particular physical properties of the material. In this operation ground water is withdrawn at a constant rate to form a shallow cone of depression in the ground water table.

Because of the density difference between the two fluids, this causes an upwelling of the coal tar, which in turn stresses the system and forces the coal tar to flow into the well more rapidly than its extremely low transmissivity would otherwise allow. Proper screening and gravel packing of the well casing assure a virtually water- and sediment-free product which can be sold as either a chemical feedstock or supplemental fuel.

Wallace, J.R., Badalamenti, S. and Ogg, R.M., "Price Landfill: Interim and Long-Term Remedial Actions", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1983, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 358-361.

The Price Landfill site near Atlantic City, New Jersey, is an inactive landfill that operated from the mid-1960s to the mid-1970s. Initially, it served as a sand and gravel pit, but when the contents had been excavated to within approximately 2 ft of the ground water level, gravel operations ceased. At that time the site began receiving private and municipal wastes. For approximately 18 months, the landfill reportedly received liquid industrial wastes, both in 55-gal drums and bulk liquids that were poured directly onto the ground. Landfill operations ceased in the mid-1970s, and at that time the landfill was covered with sand and gravel. Ground water generally flows northeast and east towards the ocean. Between the site and the ocean lie a number of privately owned drinking wells and the Atlantic City Municipal Utilities Authority (ACMUA) wellfield, which supplies drinking water to Atlantic City.

Before the summer of 1982, several actions were taken to ensure a safe supply of water until long-term remedial actions were evaluated. A water conservation program was initiated by Atlantic City. This program was very successful, and the anticipated peak demand during the summer of 1982 of 20 mgd. was never reached. The actual peak demands were approximately 15 mgd. Piping and structural modifications were installed at two ACMUA production wells to accommodate portable, truck-mounted, granular activated carbon adsorption units. These units could be used for well-head treatment in the event that contamination reached the upper Cohansey wells located near the water treatment plant. After well-head treatment, the water would be treated in the ACMUA plant. An interconnecting pipe was installed to allow Atlantic City to receive water from the NJWCo distribution system. This water would be added directly to the ACMUA clearwell and could be used to augment ACMUA treatment capabilities. Plant piping modifications were installed to allow the ACMUA to bypass the water treatment plant with the Kirkwood Aquifer supplies if the plant's hydraulic capacity became a limiting factor in supplying sufficient quantities of water to Atlantic City. The raw water quality of the Kirkwood

Aquifer is sufficient to allow discharge directly into the clearwell for chlorination only.

Two long term remedial action alternatives have been proposed for the site. Alternative 13 involves relocating 13.5 mgd of ACMUA water supply capacity north of the reservoir with a 2 mgd plume abatement well. Alternative 14b involves relocating 13.5 mgd north of the reservoir, a 2 mgd plume abatenemtn well and a slurry wall around the landfill site. Both alternatives provide: an adequate drinking water supply for Atlantic City that should not be affected by the plume from Price Landfill; positive measures to control and remove the contaminated plume; and positive measures to control the source at Price Landfill.

Walsh, J.J., Lippitt, J.M. and Scott, M., "Costs of Remedial Actions at Uncontrolled Hazardous Waste Sites -- Impacts of Worker Health and Safety Considerations", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1983, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 376-380.

In December 1980, the U.S. Congress passed legislation entitled "The Comprehensive Environmental Response, Compensation and Liability Act". This Act provides the USEPA with the legislative mandate and the money to assist in the elimination of public health hazards posed by uncontrolled hazardous waste sites. Several studies have been conducted to evaluate the types of remedial actions and associated costs applicable to Superfund sites (i.e., sites for which Superfund monies have been allocated) and other hazardous waste sites. In these studies, costs associated with health and safety of workers were either not included or not uniformly identifiable as separate cost items. As a result, the project presented in this paper was designed to specifically address the additional costs of protecting worker health and safety on a hazardous waste site. These costs do not include costs associated with addressing concerns of the public health and safety in the vicinity around an uncontrolled hazardous waste site. However, the controls and costs associated with protection of workers on the site should reflect much, if not all, of the additional costs of protecting the public in areas removed from the source of contamination (i.e., the hazardous waste site itself). The objectives of this project were: (1) to identify categories of health and safety costs; (2) collect and compile health and safety cost estimates and determine a range of costs which can be encountered on hazardous waste sites, (3) calculate percentage incremental health and safety cost adjustment factors; and (4) identify factors which impact health and safety costs and should be considered for future study and evaluation.

Wardell, J., Nielson, M. and Wong, J., "Contamination Control at Rocky Mountain Arsenal, Denver, Colorado", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1981, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 374-379.

> In response to requirements to contain or clean up contamination at Rocky Mountain Arsenal (RMA), Denver, Colorado, the Department of the Army (DA), began a program to mitigate the contamination problem at that installation in 1975. The approach initially taken by DA was to contain contamination at the installation's boundaries. In 1978, a pilot wastewater treatment system began operations at the northern arsenal boundary to remove organic contamination from ground water. The pilot system proved successful. It has been expanded to intercept all contaminated ground water crossing that boundary. A similar system is also being designed to intercept all contaminated water crossing the northwest boundary. This paper describes the history and operation of these containment systems.

Weinstein, N.J., "A Successful Underground Water Decontamination System: Its Meaning for Future Projects", Proceedings of the Second National Symposium on Aquifer Restoration and Ground Water Monitoring, 1982, National Water Well Association, Worthington, Ohio, pp. 87-93.

> This paper describes the problems encountered in an industrial plant where underground water was contaminated with 1,1,1-trichloroethane and where this contamination threatened a public water supply. The steps taken to define and resolve these problems will be described, including the development, scale up, design, installation and start up of an air-stripping system which has resulted in 99.9+ percent cleanup. Although proprietary process information is not disclosed, assessment of results are discussed in detail. The application of air-stripping to similar problems are discussed, including alternative air-stripping systems and combinations of air-stripping and adsorption as a general tool for purifying organic chemical contaminated aquifers.

Werner, J.D., Yang, E.J. and Nagle, E., "Remedial Action Management and Cost Analysis", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1983, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 370-375.

> Superfund presents a classic economic and management dilemma -- how to clean up the seemingly unlimited number of problem hazardous waste sites using limited resources. Congress' recognition of this dilemma is reflected in the Comprehensive Environmental Response, Compensation and Liability Act of 1980, by the specific statutory requirement for selection of the most "cost-

effective" remedial alternative at Superfund sites. Cost effectivenes, as out-lined in section 300.68, subpart F of the National Contingency Plan, does not mean that public health concerns should be subordinated but rather that the least cost alternative should be selected from among adequatley effective options. However, carrying out this mandate for cost effective remedies requires first, that accurate cost information be available for estimating the relative costs of remedial alternatives and second, that this information be used to implement the remedial alternative as efficiently as possible through effective planning and management. To help provide this information to the EPA's Superfund remedial action program, the Environmental Law Institute (ELI) performed detailed case studies on remedial actions at 23 hazardous waste sites across the United States. This study is the most comprehensive compilation of actual expenditure data for remedial actions that has been performed to date. For 16 of the 23 case studies, ELI worked in conjunction with JRB Associates, which compiled the technical information at the sites. This paper summarizes the findings on the costs, the planning and the management of the cleanups at these sites.

Whittaker, K.F. and Goltz, R., "Cost Effective Management of an Abandoned Hazardous Waste Site by a Staged Cleanup Approach", Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1982, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 262-267.

The Bridgeport Rental and Oil Services (BROS) site is a former oil processing and reclamation facility in southern New Jersey. The site has an overall area of approximately 26 acres, contains an 11.5 acre unlined lagoon and over 88 tanks and storage vessels, and is bounded on three sides by two fresh water ponds, a peach orchard and marshland (Cedar Swamp). A small creek (Timber Creek) running through the swamp passes in the near vicinity of the lagoon and eventually discharges to the Delaware River about 3 miles from the site. The lagoon has an average depth of 10 to 15 ft but depths as great as 60 ft in places have been reported. A thick layer of heavy oil floats on the surface. Large quantities of construction debris, trash, and several large tank trucks are partially submerged in the lagoon and all are coated with oil. Large numbers of floating drums are also present. The storage vessels on site range in capacity from a few thousand gallons to tanks with volumes of over 300,000 gal. The volume of material in each tank is not consistent. Initial site surveys have shown the majority of the tanks are either empty or contain only small quantities of bottom sludges. Two of the seven major tanks (i.e., greater than 300,000 gal) contain large quantities of liquid material.

The site poses a threat to both surface and ground water in the area. Private drinking wells in the area have been contaminated with varying amounts of volatile organic compounds. Previous breaching of the dike surrounding the lagoon has led to discharge of material to Timber Creek and the deforestation of 8-10 acres of land adjacent to the lagoon. There is visual evidence of seepage of oily materials into the surrounding fresh water ponds.

A treatment system for waters drawn from the waste oil storage lagoon. Treatment processes were recommended on the basis of laboratory and full-scale treatability tests. The most cost effective treatment solution is the application of a combined flocculation/sedimentation oil removal, activated carbon adsorption treatment system.

Williams, D.E. and Wilder, D.G., "Gasoline Pollution of a Ground-Water Reservoir - A Case History", Ground Water, Vol. 9, No. 6, Nov.-Dec. 1971.

An estimated 250,000 gallons of gasoline seeped into an underground reservoir between 1968 and 1981. Methods for cleanup include "skimming" wells to produce a high gasoline/water ratio and on-site treatment facilities. Tests on the aquifer showed a semiconfined aquifer with the confining layers being somewhat leaky. The result is multiple aquifer systems. Seventy wells were drilled to define the problem area and expedite removal. The principle removal technique consisted of packing off the lower portion of the aquifer and pumping clean water from this zone. Meanwhile, gasoline was removed from the upper zone by a smaller pump. The skimming wells pumped into separator tank assemblies. These separators were composed of density stratification tanks coupled to a flotation tank. The gasoline was stored until disposal. Only 50,000 gallons of gasoline were recovered. The authors suggest that this was because of an error in original estimates of aquifer porosity. Alternately they suggest that the lower recovery could be due to a reduction in the relative permeability of the formation to one of the fluids relative to the saturation of the other fluid. (This is current oil field technology). This was never proved by lab experiments with filter sand. Since gasoline fills smaller pores than water, clean water passed through the uncontaminated pores and produced cleaner water (when the aquifer is flushed with clean water). The final idea addressed by the authors is bacterial degradation. They state that slime is a problem in degradation. They did not analyze degradation at this site although they note that bacteria are evident at the site.

Williams, E.B., "Contamination Containment by In Situ Polymerization", Proceedings of the Second National Symposium on Aquifer Restoration and Ground Water Monitoring, 1982, National Water Well Association, Worthington, Ohio, pp. 38-44.

A unique method of containment, by polymerizing a contaminant in the ground, was successfully applied on a recent pollution control project. Approximately 4,200 gallons of acrylate monomer leaked from a corroded underground pipeline at a small industrial plant adjacent to a suburban area. A preliminary investigation of soil borings and sample analyses detected migration of the contaminant on two separate levels. The plume spread initially through a surficial zone of cinders and then passed downward through a storm sewer trench into a lower glacial sand and gravel, where the direction of migration was reversed by local ground water drainage. Below this lower level was another clay layer, which was in turn underlain by the major regional aquifer of glacial outwash. The hydrogeologic conditions did not favor recovery by conventional techniques. On the lower level, conductivity of formation materials was moderate to low and saturated thickness was only two or three feet. The upper level, although porous, was largely unsaturated. Winter weather and continuous traffic were practical considerations also. As an alternative, field testing confirmed that injection of catalysts could be used to immobilize the contaminant by polymerization and an injection program was subsequently conducted on both levels. A comparison of soil borings from before and after injection visually showed substantial polymerization and soil extractions indicated as much as a 99 percent reduction of monomer may have been obtained.

Wilmoth, B.M., "Salty Ground Water and Meteoric Flushing of Contaminated Aquifers in West Virginia", Ground Water, Vol. 10, No. 1, Jan.-Feb. 1972, pp. 99-105.

Salty ground water is commonly encountered at relatively shallow depths of 100 to 300 feet beneath the major stream channels in the western half of West Virginia. Because of the wide distribution of salty ground water and connate brine at various depths, it is difficult to distinguish natural contamination from that caused by subsurface industrial activities. Natural changes in quality apparently are minor. The available historical data indicate no large-scale natural variations in salt content during the period of record. Histories of some water well developments show unnatural large-scale increases in salt content from various industrial activities that affect the resh water zones. Some records also reveal decreases in salt content after the source of the salt was eliminated or after the subsurface activity responsible for artificial migration of the salt water was stopped.

Artesian brine contaminated a fresh water aquifer in Fayette County. Chloride content changed from 53 mg/l to more than 1,900 mg/l in a period of 5½ years. When pumping was stopped, chloride content decreased to 55 mg/l in 10 years. Heavy pumping of well fields in Charleston during 1930 to 1956 accelerated migration upward of salt water. Chloride content increased from less than 100 mg/l to more than 300 mg/l in some wells and to more than 1,000 mg/l at individual wells. Pumpage has declined greatly since 1956 and chloride content has decreased below 200 mg/l at some of the contaminated wells. In an oil field of Kanawha County, a water well was contaminated by salt water accelerated by subsurface activities. Chloride content increased from less than 100 mg/l to more than 2,900 mg/l within 2 months. After the oil-field activity was curtailed, chloride content decreased to 190 mg/l in about 2½ years. Road salt piles contaminated a carbonate aquifer in Monroe County. Chloride concentrations in wells located 1,500 feet from the piles increased from 185 mg/l to 1,000 mg/l in 5 years. The greatest change was 1,000 mg/l in 1969 to 7,200 mg/l in 1970 when the salt storage area was enlarged. All salt piles were removed in late 1970 and within 2 months chloride content decreased to 188 mg/l.

Willmoth, B.M., "Procedures to Reduce Contamination of Groundwater by Hazardous Materials", Proceedings of the 1978 National Conference on Control of Hazardous Material Spills, 1978, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 293-295.

Protection of ground water aquifers and their zones of recharge by hazardous materials is as important as the protection of surface water bodies. The zone of recharge to an aquifer can be quite vulnerable to contamination by a spilled material that presents no threat to a stream or lake. Although the source of most contaminants is surface spills, underground facilities also may leak and cause enormous damage. Thousands of small underground tanks and lines are presently exempt from regulations for prevention of spills -- including such common facilities as service stations and small heating oil tanks and distribution lines. The effects of even a very small undetected leak over an extended period can be devastating. Most often water wells nearest the spill are affected first. It is obvious then that the public should be alerted to the need for effective spill prevention regulations and contingency response procedures to reduce the serious and long-lasting degradation of ground water. New conservation and education programs should be initiated to alert the industrial and business community to the need for immediate and thoroughly effective response actions to spills of hazardous materials that may damage local aquifers. The program must show and define the critical importance of protecting the local zones of recharge to aquifers even when no threat to a stream is evident.

Wilmoth, R.C., "Limestone and Limestone-Lime Neutralization of Acid Mine Drainage", June 1974, U.S. Environmental Protection Agency, Rivesville, West Virginia.

The critical parameters affecting neutralization of ferric-iron acid mine waters were characterized by the U.S. Environmental Protection Agency in comparative studies using hydrated lime, rock-dust limestone, and a combination of the two as neutralizing agents. The advantages and disadvantages of each of these neutralizing agents were noted. On the ferric-iron test water, combination limestone-lime treatment provided a better than 25 percent reduction in materials cost as compared to straight lime or limestone treatment. Significant reduction in sludge production was noted by the use of rock-dust limestone and by the use of combination treatment as compared bo hydrated-lime treatment. Emphasis on optimizing limestone utilization efficiencies resulted in an increase from approximately 35 percent to 50 percent utilization. Studies using limestone that had been ground to pass a 400-mesh screen resulted in utilization efficiencies near 90 percent.

Wilmoth, R.C., "Limestone and Lime Neutralization of Ferrous Iron Acid Mine Drainage", EPA-600/2-77-101, May 1977, U.S. Environmental Protection Agency, Rivesville, West Virginia.

The U.S. Environmental Protection Agency conducted a 2-year study on hydrated lime and rock-dust limestone neutralization of acid mine drainage containing ferrous iron at the EPA Crown Mine Drainage Control Field Site near Rivesville, West Virginia. The study investigated optimization of the limestone process and its feasibility in comparison with hydrated lime treatment. Operating parameters, design factors, and reagent costs for both processes were determined. Effluent quality was considered of prime importance in these investigations. Coagulants were considered essential to successful thickener operation for both lime and limestone treatment. Effluent iron, suspended solids, and turbidity values could be maintained below 3 mg/l, 10 mg/l, and 10 JTU, respectively, using coagulant addition. Although the limestone process was demonstrated to be technically effective in ferrous iron treatment situations, the process was judged to be less efficient overall in comparison with lime neutralization.

Wilmoth, R.C., Mason, D.G. and Gupta, M., "Treatment of Ferrous Iron Acid Mine Drainage by Reverse Osmosis", Proceedings of the 4th Symposium on Coal Mine Drainage, 1972.

In previous research, reverse osmosis treatment of a ferrous iron mine discharge at Mocanaqua, Pennsylvania was studied. Using a tubular system, a loss of 90 percent of the original product flow in 400 hours of operation due to iron fouling was observed. Though sodium hydrosulfide flushes were successful in flux restoration, fouling immediately recurred upon resumption of operation on the ferrous water. To investigate the Mocanaqua fouling phenomena, field studies were undertaken. Reported are the results of the tests and comparisons with a spiral wound and hollow fiber reverse osmosis unit studied at the same time.

Wilmoth, R.C., Scott, R.E. and Hill, R.D., "Combination Limestone-Lime Treatment of Acid Mine Drainage", Proceedings of the 4th Symposium on Coal Mine Drainage, 1972.

The research investigated treatment methods for ferric iron acid mine drainage. One of the most promising techniques studied was combination limestone-lime neutralization. To date, neutralization has been shown to be the most economical treatment method to remove iron, aluminum, and acidity. Lime treatment has received the majority of research attention. However, limestone treatment offers several distinct advantages over lime; namely higher density, lower volume sludges, cheaper raw material costs, easier handling. Conversely, the biggest disadvantages to limestone are its relatively inefficient reaction rate.

Wilson, J.L., Lenton, R.L. and Porras, J., "Ground Water Pollution: Technology, Economics and Management", TR 208, Jan. 1976, Massachusetts Institute of Technology, Cambridge, Massachusetts.

A review of the technical, economic and management aspects of ground water pollution is presented. The ground water pollution problem is described and several of its important characteristics are pointed out. A description of the physical, chemical and biological aspects of ground water pollution is given. The technology of ground water pollution detection and observation is reviewed, including elements in the design and operation of a ground water quality monitoring system. The causes, types and extent of ground water pollution are described. These include agricultural, industrial, domestic and urban, radiological, and natural or induced sources of pollution. Methods of control for each are given. Methods of analysis as applied to ground water pollution management are described within the context of total resource management and long-range planning. Criteria for choosing among alternative plans, systems analysis, and optimization and simulation techniques are discussed. A case study of integrated ground water-surface water management with specific ground water quality considerations is described and discussed.

Wilson, L.W., Matthews, N.J. and Stump, J.L., "Underground Coal Mining Methods to Abate Water Pollution: A State of the Art Literature Review", Dec. 1970, West Virginia University, Morgantown, West Virginia.

> The report reviews published information concerning the abatement of harmful drainage from underground coal mines. Although much has been written on mine water management, very little literature is available on the specific area of preventing the formation of acid water. The references used in this report include mining engineering and hydrology studies and spans the period of time when water quantity rather than quality was the major consideration. Physical approaches to the problem of interdicting water entry into coal mines, beyond removal and treatment, are (1) land management for surface and subsurface water diversion, (b) the exploitation of water carrying strata, and (c) new mining methods. Chemical approaches to abatement include (a) the use of silica gel solutions underground to prevent acid formation, (b) the use of inert gas in active mines, and (c) the use of new and refinement of known grouting agents.

Winston, A., Kirchner, D.G. and Rosthauser, J.W., "Functional Polymers for Removal of Heavy-Metal Pollutants from Water", WRI-WVU-80-01, 1980, West Virginia University, Morgantown, West Virginia.

> This study involved designing polymeric ion-exchange resins specific for certain metal ions, with particular attention being given to systems for selectively removing iron from water. The resins are vinyl polymers bearing hydroxamic acids, a functional group having a particularly strong affinity for iron. A series of polymers was prepared in which the spacing of the hydroxamic acid groups were varied. The stability constants for the iron complexes showed that the spacing of the hydroxamic acid groups was important both in complex stability and in the selectivity of the resin for iron. The polymer having the largest binding constant for iron had an 11-atom spacing between hydroxamic-acid groups. This polymer was prepared in a cross-linked insoluble form and tested as an ion-exchange medium. The polymer removed iron from water to less than 0.5 ppm. The column could be regenerated by washing with sodium hydrosulfite or EDTA. Copolymers bearing hydroxamic acid groups undergo cross-linking in the presence of iron, resulting in large increases of viscosity and in flocculation. Polymers for binding copper and mercury were synthesized and evaluated. The functional group for copper was the tripeptide glycylglycylhistidine. For mercury, polymers containing sulfide were studied. Preliminary evaluation showed that the polymers formed complexes with copper and mercury, respectively. Various applications of these resins in environment, health, and industry were suggested.

Wood, P.R. and DeMarco, J., "Treatment of Groundwater with Granular Activated Carbon", Journal of the American Water Works Association, Vol. 71, No. 11, Nov. 1979, pp. 674-682.

Removal of halogenated organic compounds, total organic compounds, trihalomethane formation potential and several high molecular weight compounds from raw, lime softened and finished water by using granular activated carbon (GAC) has been studied for a three year period at the Preston Water Treatment Plant in Hialeah, Florida. Ground water is the sole source of drinking water in this region. Total organic carbon (TOC) of the ground water is about 10 µg/l and trihalomethane formation potential (THMFP) ranges from 650 to 950 µg/l, THMFP and halogenated organic compounds of the finished water in the 300 µg/l and 330 µg/l range respectively.

The effectiveness of four types of GAC in removing these organics was evaluated. Carbon 1 was tested in beds of 0.75, 1.5, 2.25 and 3 m deep with empty bed contact times (EBCT) of 6.2, 12.4, 18.6 and 24.8 min. Carbons 2, 3 and 4 were tested in beds of 0.75 m deep with an EBCT of 6.2 min. each. Chloroform removal from finished water showed that equal volumes of the four types of GAC removed 78% (carbon 4), 53% (carbon 1), 48% (carbon 3) and 40% (carbon 2). On an equal weight basis, carbon 4, 3, 1 and 2 removed 78, 57, 56 and 36 percent respectively. The removal for eighteen other purgeable halogenated organic compounds rated the carbons in a similar order. Removal of THMP substances from finished water showed that, during a 59-day test period, an equal volume of four types of GAC removed 27 (carbon 2), 26 (carbon 1), 16 (carbon 3) and 8 (carbon 4) percent of total THMFP entering the water. On an equal weight basis carbons 1, 2, 3 and 4 removed 26, 23, 18 and 8 percent, respectively.

The level of total trihalomethanes reaching a consumer's tap was simulated by rechlorinating water from GAC column to 3 µg/l of free chlorine and bottle-aged two days. The four types of GAC were evaluated at equal depths of 0.75 m with a bed life of ten days. At an equal volume basis, carbons 1, 2, 3 and 4 removed 54, 35, 14 and 9 percent of the THMFP substances. TOC removal showed a similar order of removal. The water was also spiked with high molecular weight industrial and agricultural chemicals for evaluating the adsorption capacities of the GAC. Chlorinated pesticides exhibited early low level breakthrough. Overall, more than 80 percent of the spiked high molecular weight compounds were removed. Removal of 2-nitrobenzene, ethyl benzoate, naphthalene, 1-chloro-2-nitrobenzene, dimethylphthalate and diisobutylphthalate ranged from complete to poor.

Yaniga, P.M., "Alternatives in the Decontamination of Hydrocarbon Contaminated Aquifers", Proceedings of the Second National Symposium on Aquifer Restoration and Ground Water Monitoring, 1982, National Water Well Association, Worthington, Ohio, pp. 47-57.

Hydrocarbon contmaination of ground water is a widespread problem of increasing concern. Hydrocarbons in ground water affect both domestic and public water supplies, resulting in significant economic losses, both to the water owner and the hydrocarbon owner. The severity of the problem can range from the objectionable tastes and odors imparted by small amounts of dissolved hydrocarbons to the destruction of aquifer usability through the accumulation of a considerable thickness of hydrocarbons on the top of the water table. The application of sound hydrogeologic principles is the key to rehabilitating hydrocarbon-degraded aquifers. The extent and magnitude of contamination are defined on the basis of observation wells, isopach maps and other devices. One of the major problems in analzing the problem is to distinguish between the real thickness and apparent thickness of the hydrocarbon lens or free product. Groundwater Technology Inc. has successfully applied several techniques to the recovery of lost product and the abatement of residual, dissolved hydrocarbons. Among these are: (1) a special two-pump system that utilizes water/hydrocarbon-sensitive probes and oleophilic/hydrophobic filters that efficiently retrieve the free product that floats on water; and (2) processes that involve air-stripping, granular activated carbon filters and biochemical processes that efficiently lower the dissolved hydrocarbon concentration of ground water. The successful application of these techniques is described in the context of case histories of several projects completed by Groundwater Technology Inc.

Yaniga, P.M. and Demko, D.J., "Hydrocarbon Contamination of Carbonate Aquifers: Assessment and Abatement", Proceedings of the Third National Symposium on Aquifer Restoration and Ground Water Monitoring, 1983, National Water Well Association, Worthington, Ohio, pp. 60-65.

The words assessment and abatement in the past few years have become terms of major significance in the yet-to-be-compiled encyclopedia of ground water contamination. That same encyclopedia, when compiled, will contain under the lead "ground-water contamination", a category designated "hydrocarbon losses to ground water: definition and cleanup". Under that section title will doubtless appear subheadings labeled: (1) geologic considerations in contamination assessment and abatement: consolidated vs. unconsolidated rock types; (2) structural influence and control on hydrocarbon movement in the subsurface: fracture and joint set control; and (3) lithologic considerations in fractured bedrock porosity and permeability: carbonate vs. noncarbonate rock types. This paper discusses one case history in which each of those noted headings came to play a significant role in the assessment and abatement of a hydrocarbon loss to ground water. The loss of a leak of No. 2 fuel that occurred over a prolonged period through a subsurface fuel transfer line. The loss area was underlain by a consolidated bedrock unit of regional extent that is locally tapped as an aquifer. The geologic unit is a steeply dipping, locally well-jointed carbonate rock. This structure and lithology restricted the plume configuration and its direction of movement to a narrow, linear band. Apparent product thicknesses in observation wells within the plume appear joint-set and solution-channel controlled, showing values approaching 60 feet. Comprehensive evaluation and assessment of the geologic controls affecting the plume culminated with the development and enactment of a program of water-table manipulation that is controlling product movement and retrieving the fugitive product for reuse.

Zaval, F.J. and Robins, J.D., "Water Infiltration Control to Achieve Mine Water Pollution Control -- A Feasibility Study", Jan. 1973, West Virginia Department of Natural Resources, Charleston, West Virginia.

The study determined the feasibility of conducting a full-scale demonstration to document the effectiveness of land reclamation at mined-out areas in establishing surface water infiltration control to prevent acid mine water pollution. The study site was the Dents Run Watershed, Monongalia County, West Virginia. Investigative measures included: investigation of each mine area and opening; a detailed description of each site; sampling and analysis of all receiving streams and discharge points to determine the severity of acid mine water pollution; and evaluation and selection of weir structures, monitor enclosures and instruments to be placed in unattended areas to provide a continuous record of stream conditions. Recommendations and cost estimates are presented for reclamation at each site and for the installation of monitoring facilities.